CATHODE INTERFACE IMPEDANCE GROWTH AT ELEVATED TEMPERATURE

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by

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PREFACE

The work to be described in this paper was done at the General Electric Company Receiving Tube Plant, Owensboro, Kentucky during the period 3 January to 14 March 1955.

The general trends of cathode interface impedance growth and many details in connection with the effects of temperature variation, cathode current density, and base metal impurity content have been investigated by several people working in the field of cathode research. The greatest portion of this information considers the trends over several thousand hours and under poerating conditions ranging from very high to very low dutys. A large amount of research has been done in an effort to determine the physical and chemical nature of the interface layer.

It is the purpose of this investigation to examine more closely the cathode interface growth in the early life of the tube and to attempt to correlate both the electrical and the physical growth with (1) Operating temperature, (2) Cathode current density and electric field intensity, (3) Previous life experience, and (4) Impurity content in the base metal alloy.

The writer wishes to express his sincere thanks to the personnel of Design Engineering, General Electric Company Receiving Tube Plant for the fine cooperation afforded him in his work and for the many stimulating discussions in connection with the work being done. Particular thanks is expressed to

Mr. A. P. Haase, Manager of Development Engineering for his strong interest in the project and for his able guidance and assistance in the planning and carrying out of the program of interface life testing which this paper describes. For his suggestions, and encouragement in the preparation of this paper the writer wishes to thank Mr. J. J. Downing of the Naval Postgraduate School.

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CHAPTER I

INTRODUCTION

1. A Brief History of Cathode Interface Investigation.

The existance of a cathode interface layer in oxide coated cathodes is believed to have first been investigated during World War II in connection with sparking in high current pulsed diodes, especially magnetrones. Reports on this work have been published by Eisenstein, [5] by Fineman and Eisenstein, [7] and by Danforth and Goldwater. [3] Since this initial work many of the cathode "sicknesses" plaguing oxide coated cathodes have been attributed to the interface. Further studies of the cathode interface have been made by Eisenstein, [6] Rooksby, [15] Child, [2] Eaglesfield and Douglas, [4] Bartley and White, [1] Frost, [9] Wagner, [18] Matheson and Nergaard, [13] Weber, [20] Waymouth, [19] and others.

2. Cathode Interface Model.

Electrically the interface is generally taken to be equivalent to a parallel resistance-capacitance circuit in series with the cathode lead although the actual equivalent circuit has been demonstrated to be more complex in most cases. Although not exact, the simple R-C circuit serves very well for most purposes of study and evaluation. R-C time constants ranging from 0.03us to 0.5us are encountered and resistances from a few ohms to of the order of 1000 ohms have been measured.

Interface resistance appears earlier in the tube life and develops more rapidly as operating temperature is increased. The presence of current tends to retard the growth of resistance to the extent that at normal operaring temperatures and currents most tubes develop very little if any interface resistance but if operated cut-off the tendency is very much increased. The presence of impurities in the sleeve metal alloy has a decided effect in that such elements as aluminum, titanium, magnesium, zirconium, molybdinum, silicon, and tungsten in very small alloying quantities increase the liability to interface development quite noticeably. However silicon has been found to be the most detrimental by a substantial margin, and in most commercial tubes it is the only element giving rise to an interface compound.

The mechanism by which this interface forms has been generally accepted as a chemical reaction between the oxide coating compound and silicon which migrates to the coating-sleeve interface. The reactions are as follows:

$$2BaO + Si \dashrightarrow 2Ba + SiO_2$$

and

$$2BaO + SiO_2 \dashrightarrow Ba_2SiO_4 \quad \text{(barium ortho-silicate)}$$

Barium orthosilicate has been identified by x-ray diffraction methods by Eisenstein, [6] and by Rooksby. [15]

The electrical properties described above are explained by considering the properties of barium orthosilicate as an

impurity activated semi-conductor. When the cathode is activated an excess of barium is distributed throughout the crystal lattice of the cathode coating. As the interface layer grows some of the free barium diffuses into the crystal lattice of the barium orthosilicate and serves to activate the material. In the absence of current the free barium atoms tend to diffuse down temperature gradient which is away from the interface region and so a deactivation process results. If the tube is conducting current the barium atoms acting as donors at the surface of the cathode become positive ions and so have a tendency to diffuse back toward the cathode sleeve and thus into the interface region producing an activation process. The balance reached when the diffusion rate of the ions toward the sleeve matches the diffusion rate down temperature gradient determines the extent to which the tube develops interface resistance assuming that the thickness of the interface layer is fixed. The thickness of the interface layer and the rate at which it forms appear to be functions of the percentage of silicon in the sleeve metal alloy and the temperature at which the tube is operated. Frost states in Project Whirlwind Report R-179, June 29, 1950 that

> When the heater potential is increased to 20% above normal, the acceleration appears to be at least one order of magnitude and perhaps more.

although the barium orthosilicate interface is generally accepted there is at least one notable exception to this agreement. Weber [20] states on the strength of his x-ray examination of "crusts" which he identifies as the interface compound:

From their identity, it is justified to conclude that the crusts are nothing but a part of the emission layer which somehow became sintered to a crust on the cathode, and that the crusts do not consist of any barium compound as described by Rooksby and Eisenstein.

The thickness of the interface layer has been measured and found to range from about three to ten microns. These values are generally agreed upon.

Because of the tendency towards interface development in high silicon nickel cathodes there has been a trend toward the use of Normal and Passive nickel alloys in the manufacture of cathodes for receiving tubes. At the present time it is estimated that approximately 75% of all receiving type tubes have Normal cathodes and that the remaining 25% are about equally divided between Active and Passive. These percentages are believed to represent within 10% the practice at the present time in most of the major tube manufacturing plants.

3. Summary of Experimental Results.

The outstanding causes for variation in interface growth at elevated temperatures were found to be operating temperature and previous life experience, with operating current playing a less important part, and field intensity having no appreciable effect. The effect of operating temperature was found to be essentially as predicted by the work of other investigators. The effect of previous life experience was to accelerate the growth of the interface resistance in the case of those tubes which had had substantial operating time under

conditions of moderately elevated temperature and normal class A-1 current. An interesting phenomenon was observed in that tubes operating at elevated temperatures were more liable to interface growth when conducting a small amount of current than when operating cut-off or with normal class A-1 current.

The acceleration encountered in the "previous life" tubes suggests that interface life testing might be performed on tubes having completed a few hundred hours of regular life testing thus reducing the number of tubes tied up in test, and that a further saving might be effected in time by operating these tubes at elevated temperatures and thus accelerating the interface development further in this manner.

CHAPTER II

PROGRAM OF INVESTIGATION

1. Outline of the Program.

The investigation was broken down into two basic programs. The first program made use of tubes which were carefully controlled at their source such that as far as possible the materials, assembly, and processing were identical. This proceedure was followed in order to eliminate to a substantial degree any variations arising from differences in individual tubes or individual tube lots and so guarantee to the greatest extent possible that variations in the interface growth would be caused by variations in the life experience of the tubes only. These controlled tubes were divided into four groups each of which was subjected to a different "previous life" and then further divided into two groups to operate at different temperatures under the special life test conditions which included two conditions of no current flow, one condition of normal class A-I current, and one condition of approximately ten percent normal current. Sample tubes were removed from the life test program at various points in time and set aside for physical examination by microscopic, chemical, and x-ray diffraction methods. Throughout the special life the interface impedance growth was monitored by periodic measurement of each tube. The following block diagram shows the program of this experiment.

PROGRAM OUTLINE FOR FIRST EXPERIMENT

Controlled Mounts
Materials & workmanship
alike - built in sequence
with no time lapse

E. Pumped and Sealed
Baked-400°
Unbaked

A. Pumped and Activated
(Extra tubes available)

Physical Examination
Microscopic
Chemical
X-Ray Diffraction

B. Normal Ageing Schedule
(Extra tubes available)

C. 60 Hour Life - Normal
Class A_1 conditions except
elevated heater temperature
$E_h = 7.5V$

D. Extend to 300 Hour Life
conditions as above

Special Life Operation

Temperature		Electrical		
2.	$E_h = 7.5V$	Normal A-1	a.	$E_b = 180V$ $I_b = 8$ ma
3.	$E_h = 10V$	Zero	b.	$E_b = E_c = I_b = 0$
		Hard C.O.	c.	$E_b = 180V$ $E_c = -30V$ $I_b = 0$
		Near C.O.	d.	$E_b = 250V$ $I_b = 1$ ma

Measure at 0, 10, 30, 60, 100, 200, 400, 600, 800 Hours

A small group of tubes having completed 1000 hours of life testing were used as a broad control operating under two different temperatures and with no cathode current.

The second basic program was set up to examine the effect of various cathode alloys on the interface growth. Using a standard test triode structure, tubes alike in all respects except for the base metal alloy of the cathode were to be constructed. The cathodes were made using five different alloys: 499 Nickel, 220 Nickel, 599 Nickel, 225 Nickel, and Grade "A" Nickel. These cathodes were fitted with moly-nickel thermocouples and sprayed with the same double carbonate coating used in the tubes of the first program. Plates, grids, and micas were obtained but shortage of time prevented further progress with this program.

Shortage of time also prevented any extensive physical examination of the tubes of the first program however the investigation is a continuing project and the work of physical examination and special tube building and testing will be carried on.

CHAPTER III

THE LIFE TEST PROGRAM

1. The Controlled Tubes.

The tube selected as the test vehicle for the life test program was the development type Z-2177 which is a special double triode developed for use as a computer tube. At the time of this writing no industry-wide designation has been assigned to this tube, however the I.B.M. Co. has assigned the number 0528 as their part number. The Z-2177 was selected for the following reasons: there are two cathodes per tube; there was a substantial amount of test data already accumulated on this type which showed a tendency toward mild interface development at normal temperatures after several thousand hours of operation; the cathode used was of 220 Nickel which is a Normal alloy thus placing it in the intermediate region between Active alloys and Passive alloys and as noted previously among the more commonly used cathode alloys; the tubes were immediately available from local production, and interest in the type was quite high.

The Z-2177 ia a nine-pin miniture double triode in a T6½ 2 3/8" envelope. The plate is of aluminum clad iron. The grid is formed (round). The grid to cathode spacing is approximately 4½ mils. The cathode is round, seamless, 220 alloy nickel. The melt lot for all cathodes was #90 and the

manufacture date was April 1954. The manufacturer was Superior Tube Company. The total cathode area is approximately 0.66 cm^2 and the coated area is approximately 0.56 cm^2. The cathode spray used was a standard double carbonate G. E. specification number *H1 1N. The heater voltage and current for one section are 6.3V. and 225 MA. The average operating characteristics, cathode melt lot analysis, and cathode spray materials list may be found in the Appendix.

The tubes used in the life test program were obtained from regular production. The mounts were made in sequence on 13 January 1955 and the tubes were pumped, activated, stabilized, and tested on 14 January 1955.

The tubes were marked in accordance with the four unit code outlined on the following page. The first column indicates the extent of "previous life" operation prior to entry into the special life operation described by columns two and three. The actual operating conditions described by the items in column three are as listed under Special Life Operation, Electrical in the PROGRAM OUTLINE FOR FIRST EXPERIMENT on page seven. The construction schematics for the life shelves providing these operating conditions are included in the Appendix. The fourth column shows the individual tube number and so indicates the number of tubes

TUBE IDENTIFICATION CHART

THE TUBES ARE MARKED AS SHOWN WITH SLINK INK ON A SAND-BLASTED SECTION. THE FOLLOWING CHART KEYS THE IDENTIFICATION.

A. Zero Life Pumped and Activated Tested for: H-K Leakage, Gas, Shorts, Opens, and Cut-off	1. Pulled before Special Life		1,2,3,4
	2. Eh = 7.5V	a. Normal A-1	1,2,3,4,5,6
		b. Zero	1,2,3,4,5,6
	3. Eh = 10V	c. Hard C.O.	1,2,3,4,5,6
		d. Near C.O.	1,2,3,4,5,6
	4. Extra tubes		1,2,3,-----
B. Zero Life Pumped and Activated, 13 min Stabilized Tested for: H-K Leakage, Gas, Shorts, Opens, Cut-off, 5.5-11.5 ma- 6.3V, 180V,-2V	1. Pulled before Special Life		1,2,3,4
	2. Eh = 7.5V	a. Normal A-1	1,2,3,4,5
		b. Zero	1,2,3,4,5
	3. Eh = 10V	c. Hard C.O.	1,2,3,4,5
		d. Near C.O.	1,2,3,4,5
	4. Extra tubes		1,2,3------
C. 60 Hr Life 7.5V, 180V. 8 ma Pumped, Activated Stabilized and Tested as in B above	1. Pulled before Special Life		1,2,3,4
	2. Eh = 7.5V	a. Normal A-1	1,2,3,4,5
		b. Zero	1,2,3,4,5
	3. Eh = 10V	c. Hard C.O.	1,2,3,4,5
		d. Near C.O.	1,2,3,4,5
D. 300 Hr Life 7.5V, 180V, 180ma Pumped, Activated, Stabilized, and tested as in B above	1. Pulled before Special Life		1,2,3,4
	2. Eh = 7.5V	a. Normal A-1	1,2,3,4,5
		b. Zero	1,2,3,4,5
	3. Eh = 10V	c. Hard C.O.	1,2,3,4,5
		d. Near C.O.	1,2,3,4,5
E. Zero Life Pumped and sealed, not activated	1. Not baked		1,2,3,4,5,6,7,8
	2. Baked -400 Degrees		1,2,3,4,5,6,7,8
	3. Open two days then baked -400 Degrees		1,2,3

included in each life test group. Referring to the chart it can be seen that an extra tube was included in each group under "previous life" A since it was not practical to test for plate current before the stabilizing process was used. As shown under B the test for plate current required that Ib lie between 5.5 and 11.5 ma when operated at 6.3V. Eh, 180V. Eb, and -2V. Ec. The group E was included to provide a chemical and physical control for comparison with tubes which had been processed. Tubes preserved for future examination are usually baked as they are pumped at 400 degrees. In order to determine if this baking might have an effect on the chemical composition of the cathode coating some where baked and an equal number were pumped and sealed without baking. The extra three were left open for two days because the pumps were full. The stabilizing process mentioned above is normally used on all Z-2177 tubes. The omission of this process was the only difference between "previous life" group A and group B. The process consists of the following 13 minute schedule: Eh---8V.---1 minute, Eh---12V.---, 2 minutes, Eh---8V.---5 minutes, Eh---7V.---Ib---15MA---5 minutes. The conditions of operation during "previous life" for groups C and D were 7.5V. Eh, 180V. Ebb, approximately 8MA. Ib obtained using cathode bias.

2. Interface Special Life Test.

Following the "previous life" operation the tubes

were started upon their special life. These tubes were measured for interface resistance and capacitance at the beginning of this period of special life operation and at the following times during this life: 10, 30, 60, 100, 200, 400, and 600 hours. The A group was an exception to this schedule to the extent that a measurement was made at three hours on this group and none was made at 60 hours. The reasons for this departure were that there was no interface growth for a period of much longer than three hours in the A group and there was a wide gap in the information between 30 and 100 hours so it was decided to do away with the three hour reading and add a 60 hour reading on the future groups. The A group also was read at 440 hours in the case of the 7.5V. Eh tubes in order to determine if there might be any radical tendency in the growth of the interface which was first measured in these tubes at 400 hours. There was no such tendency.

There were one or two occasions upon which time was lost on the shelves but this was of no consequence since each shelf was interlocked and fitted with an elapsed time clock which made it quite simple to replace the time lost by simply running the shelf for the additional time necessary to bring that shelf up to the required time of operation.

One area of data was lost as a result of cathode deterioration. The group of tubes operating with 10V. Eh

and conducting Normal A-1 current ran away on the shelves as a result of grid emission. The grid return resistor used was 470,000 ohms and so developed a substantial counter bias when grid emission occurred. The tubes which suffered this operation failed to the extent that the test current required on the test set could not be obtained even at zero external bias. It was believed that this loss of emission was a result of the deterioration of the cathode resulting from excessive current so steps were taken to insure that even should grid emission occur there would be no loss of bias. Four tube sections were operated with a grid return of zero ohms and four tube sections were operated with a grid return of 47,000 ohms. Neither of the operating conditions thus used allowed the tubes to run away but the same deterioration of the cathodes was encountered. This pointed up a very interesting fact: That at high temperature, operation of a tube with current is more deleterious to cathodes than if the tube is operated with zero current. This observation will be discussed further in the chapter treating the conclusions arrived at as a result of this work.

The loss of this data makes all the information resulting from the 3a tubes of all groups practically useless as far as any comparison with other data is concerned since the actual current during operation before failure is not known, and the deterioration of the cathodes in these tubes makes measurements obtained prior to failure open

to question as to their actual meaning.

The small group of tubes which were obtained with 1000 hours of life were operated on an auxiliary shelf of thirty sockets in two conditions of zero current and at two different heater potentials. Section one(pins 5, 6, 7, and 8) was operated with 10V. Eh and with all other elements tied to ground while section two(pins 1, 2, 3, and 4) was operated with 7.4V. Eh with plate and cathode tied to ground and grid tied to -45V. Measurements were made at zero, three, 21.25, 49.5, 188, 428, and 784.5 hours. This group of tubes was used primarily as a broad control group to predict trends in the actual main test group and so enable one to adjust the experimental proceedure as necessary to highlight these trends if such adjustment might be indicated.

3. The Life Test Rack.

The life test rack used was a standard rack built to accomodate five shelves but not set up for heater cycling. Three shelves were used. Two of these shelves were operated at 7.5V.Eh to supply the "previous life" (2a) condition and the b, c, and d conditions of operation at 7.5V. Eh. One shelf was operated at 10V. Eh supplying the a, b, c, and d conditions of operation at this heater voltage. As mentioned before the construction schematics for these shelves are to be found in the Appendix. The schematic for the special shelf used for the group of tubes received with 1000 hours life may

also be found in the Appendix.

4. The Interface Test Set.

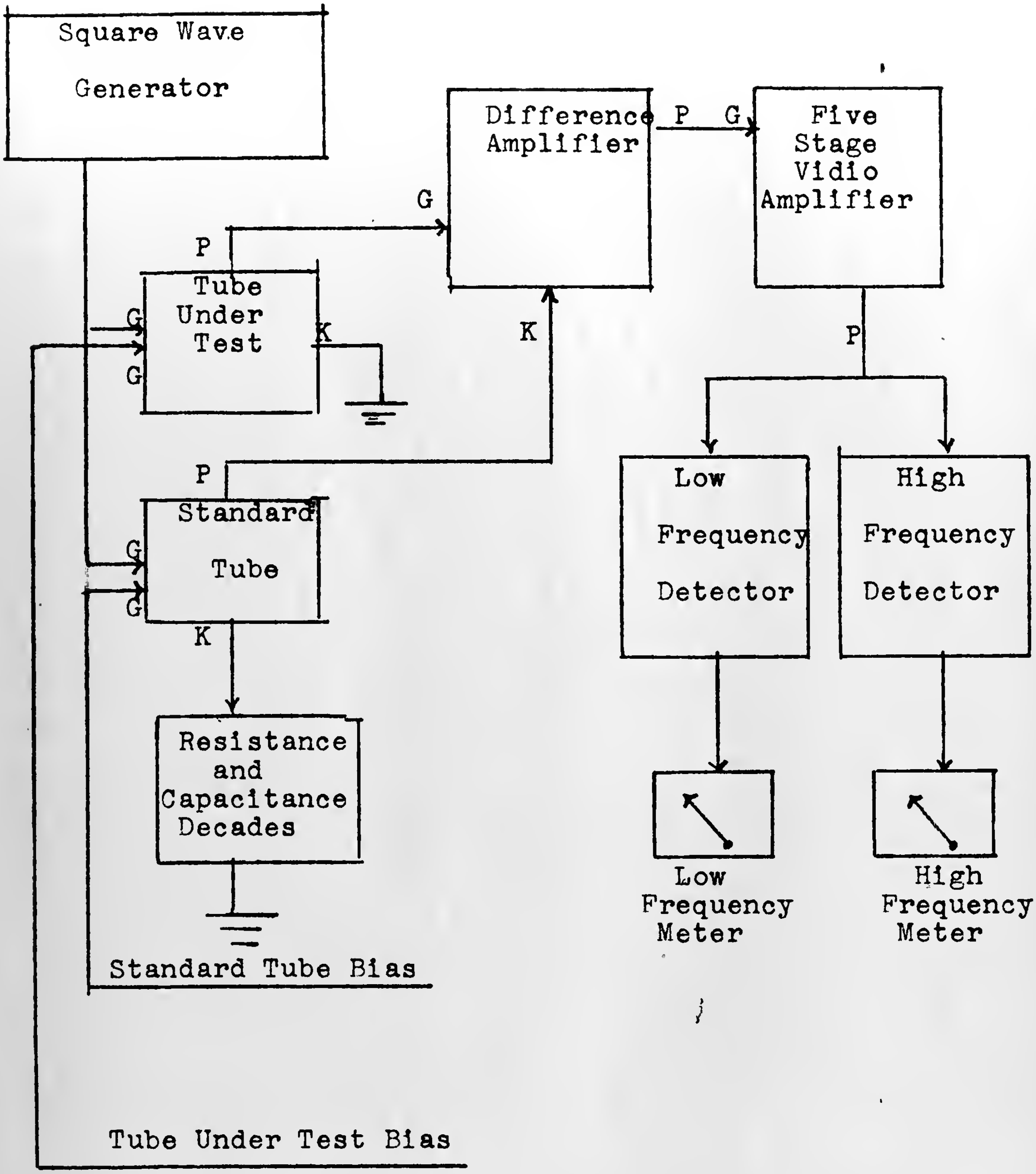
Two measurement equipments were available. One of these test sets operated according to the Wagner two-frequency principle wherein the plate resistance of the tube under test (TUT) is determined at a high frequency such that the interface capacitance may be assumed to bypass the interface resistance. This value of resistance is then used to simulate the plate resistance of the TUT, and at a low frequency, such that the effect of the interface capacitance may be considered negligable, the value of the interface resistance may be determined by substituting in the simulated tube circuit a value of resistance which results in the same performance as that of the TUT. This system gives quite satisfactory results on most tubes but it does not give any information as to the interface capacitance.

The second test set available was designed by W. U. Shipley of General Electric Co. This set makes use of a standard tube and the degeneration caused by the interface impedance. A small amplitude square wave is applied simultaneously to the grids of the standard tube and the TUT. The low frequency gains of the two tubes is made equal by adjusting the bias on the standard tube and a resistance inserted in the cathode circuit of the standard tube. The high frequency gain is then adjusted in the standard tube

by adjusting a capacitance across the resistance in the cathode circuit of the standard tube. When the high and low frequency gains have been made equal for both tubes the equivalent interface resistance and capacitance are the values inserted in the cathode circuit of the standard tube. The actual method used to achieve this result involves the use of a difference amplifier, a high gain broad band amplifier, and two indicator circuits. A block diagram of the equipment is presented on the following page. The schematic diagram of the test set is included in the Appendix. This test set was selected for the project work.

When it was found that the time constants encountered in the product of the interface resistance and interface capacitance, as obtained through measurement using the Shipley tester, were of the same order as the rise time of the square wave used in the tester it was suspected that there might be some discrepency in the values obtained in the measurements. The square wave characteristics were obtained and are presented in the Appendix. It was decided to run calibration curves for short time constant interface impedances on the test set in order to determine the extent of the validity of the test data obtained in the measurements. Using a tube known to have no interface impedance, simulated impedances were inserted into the cathode circuit of the TUT and the measurement proceedure was carried out as in the case of tubes actually having interface. In the case of very short

INTERFACE TEST SET BLOCK DIAGRAM



time constants a very broad null was encountered in the sense that there was a considerable range of values over which a complete null could be obtained. The resistance and capacitance measured at each extreme of this broad null were recorded and in the construction of the curves these extremes were plotted. In the case of the double entry curves of Fig.3 the values at the lower extreme of the null were used.

Following the construction of the test set calibration curves, the test data was examined in the light of these curves, and the following points were noted:

1. The vast majority of the test data lies in the region between 0.04us and 0.1us (see Fig. 3). There are a few points which lie below 0.04us and several points, notably in the low R values in the lower temperature tubes, which lie above the 0.1us curve.

2. Referring to Fig. 1 it is seen that the width of the null, expressed as the variation in resistance read compared to the actual resistance of the sample, ranges from about 20% at 0.03us to a very small amount - only a few percent at most- at 0.1us.

3. Although the test data lies principally in the region between 0.04us and 0.1us, the characteristic of a broad null in the sense of the remarks in 2. above was encountered only very seldom and then primarily at low values of R. This fact along with the consideration that Fig. 3 was constructed from values at the lowest resistance null leads to the conviction that the

test data in all likelihood would lose rather than gain significance if it were to be modified by the application of the calibration data.

4. Considered in a slightly different manner; the test data, though obtained by adhering to the established technique of reading at the lowest resistance null, is probably much less in error as equivalent parallel RC than would be indicated by reference to Fig. 1 or Fig. 3 since the lack of the broad null puts the data well above the lower curve of the 0.03us data in Fig. 1 and in the region of the 0.1us data where the broad null is not present. From here then one may refer to Fig. 3, remembering that this data too is derived from the lower value side of the null, and find that at 0.1us the correction required for both R and C is quite small.

5. The reason for the difference in the null characteristics of an actual tube and the simple RC simulation undoubtedly lies in the fact that in most if not all cases the actual equivalent interface impedance circuit is more complex than a simple parallel RC; having cascaded parallel networks and RC series branches as well.

6. As it is the relative trends that it is desired be examined, it is felt, considering the above discussion, that this can best be accomplished by working with the raw data and remembering the limitations which are imposed by both the imperfect simulation of the interface impedance and by the operation of the measuring equipment near the lower limit of its capabilities insofar as RC time constants are concerned.

CHAPTER IV

LIFE TEST RESULTS

1. Considerations on Data Presentation.

The volume of data obtained from the program outlined in the previous chapters was found to be quite substantial and careful consideration was given to the determination of the most effective method of presentation of this data. For each section of each tube at each measurement the interface resistance, interface capacitance, and grid bias required to produce 2.5MA plate current with 125V. Eb were recorded. The measurements were made with 4.8V. Eh and in each case where an interface was measured the measurement was repeated with 5.8V. Eh in order to obtain data on the variation of resistance with cathode temperature. The data on grid bias was expected to furnish some very interesting information as to the rate of interface resistance formation by showing a reduction at sucessive measurements corresponding to the cathode bias produced by the interface resistance. However upon examination of the data it was found that there were some far more radical effects upon the bias than could be referred to the changes in interface resistance. Two of these effects which far overshadowed any variation which might result from changes in interface resistance were changes in contact potential during the early stages of the tube life and loss of cathode emission in the late stages of the tube life. Because of these

effects any use of the bias tendencies further than as a prediction of impending tube failure during the testing period was not considered feasible. There was no question as to the presentation of the resistance data but the best method of showing the capacitance development was pondered considerably. Since the time constant associated with the interface impedance is the determining factor in the effect of the interface on the dynamic operation of the tube it was decided that this was the best factor to use to demonstrate the effect of capacitance development.

The data in curve form may be found in the Appendix. The interface resistance versus time was plotted from the raw data and appears in three forms. One group of curves shows individual sections of tubes. A second group of curves shows the average of all sections in each group of tubes having the same life history. A third group of curves is presented in three parts using average curves from the group of the preceding sentence and is arranged to show the effects of 1. Field intensity and operating cathode current, 2. Operating cathode temperature, and 3. Previous life experience.

The interface resistance-interface capacitance time constant versus time was plotted from computed values using the raw data and appears in two forms corresponding exactly to the second and third groups of curves described for the resistance data presentation.

A key to the interpretation of the curves is presented on the following page.

KEY TO CURVE INTERPRETATION

Scale: The abcissa is always time read directly in hours - maximum scale reading is 600 hours. The ordinate is either resistance read directly in ohms - maximum scale reading is 300 ohms, or RC time constant.read directly in millimicroseconds - maximum scale reading is 300 millimicroseconds, or 0.3 microseconds.

The code at the upper left-hand corner of the page gives the information necessary to identify the curves presented. The code follows directly from the Tube Identification Chart showing: Previous life (the first letter which is a capital), Operating heater voltage (The first number), and Operating condition (The small letter following the first number.) Following the Tube Group identification is either 4.8 or 5.8 which tells whether the interface test was made using Eh = 4.8V or Eh = 5.8V. Next, if the curve, or curves, is plotted for average values in the group, the word Average appears. If it does not, then the curves are for individual sections in the group, and they are identified by two digit numbers on the curves; the first number identifies the tube and the second the section of that tube. Last in the code at the upper left-hand corner of the page comes either R or RC which tells whether the curve or curves are Resistance versus Time or RC versus Time.

Points shown as ø represent averages obtained from data having fewer than half the original number of samples present in the averaging process.

2. Interpretation of the Results.

There appeared to be little reason for presenting individual time constant curves since the principal information obtained from the individual resistance curves was that the individual nature of the tubes prevailed in spite of the carefully controlled history of these tubes, and examination of the data showed that presentation of individual curves of time constant versus time would do no more than lend emphasis to this individuality.

The graph paper used is approximately second power paper in both dimensions and serves to emphasize any variation in the early life of the tubes. In examining the plotted results it must be kept in mind that the information, with the exception of the individual resistance group, is average data and that because of the wide variation in a given group a substantial and consistent variation between average curves is required to signify a difference in effect. A second point to be kept in mind is the fact that the accuracy of the test set at low values of resistance is not much better than plus or minus five ohms below about ten ohms although the repeatability is substantially better than this. Thus the trends may be considered as reasonably accurate but the data above ten ohms or so must be considered appreciably more reliable than that below this value.

Further discussion concerning the interpretation of the results as expressed in the curves will be found in the chapter treating conclusions drawn from these results.

A group of curves showing the effect of "previous life" was plotted for the tubes which were received with 1000 hours life and used as broad control tubes. These curves may be found in the Appendix. The following information is necessary in the interpretation of these curves. The groups numbered 101 and 102 were received with 1000 hours regular life which is operation with 6.3V. Eh, 180V. Eb, and a cathode bias resistor of 140 ohms. This represents operation at approximately 2.2 watts plate dissipation which is the maximum rated value. The group numbered 104 was received with 1000 hours ØIp life which is operation with 6.3V. Eh, 180V. Ebb, 3,900 ohm plate load, and grid returned to plus 180V. through 3.9 megohms. This is zero bias operation. The group numbered 106 was received with 1000 hours Ipco life which is operation with 6.3V. Eh, 180V. Eb, and -50V.Ec. This is cut-off operation. The code at the upper left-hand corner of the page describes the curves presented in the same fashion as in the case of the main group of curves. The number 1 or 2 following the "previous life" listing refers to the section of the tubes and so indicates the operating condition during special life as described on pages 14 and 15. In the case of the data on these tubes the 600 hour scale on the graph paper was too short and so was extended to 800 hours. The 800 hour point is in correct scale and the points plotted at 784.5 hours are also in correct scale but there is no correlation in the lines intermediate between 600 and 800 hours.

CHAPTER V

CONCLUSIONS

1. General.

The effects of 1. Field intensity, 2. Operating cathode, current, 3. Operating cathode temperature, and 4. Previous life experience may be determined from examination of the comparison curve groups showing Average R and Average RC, and the Individual R curves showing mainly the extent of the variation from one tube section to another within the same life group.

2. Time Constant Considerations.

The RC values lie principly between 0.04 us and 0.1 us with few values below 0.04 and several above 0.1. There is only one value above 0.1 earlier than 400 hours and generally the trend is to start at a value in the vicinity of 0.05 us and rise gradually with time until reaching a value near 0.1 us. Examination of the comparison groups shows no major consistent variations which could be attributed to any of the four causes being investigated. The tendency to rise with time and the general consistency throughout are considered to be the main significant factors in the consideration of the values of RC. It can also be taken as a general factor in evaluating the comparison groups in resistance that the measurement at any one time is equally valid for all groups since there is no consistent variation of RC imposing a range of time

constants which would unduly shade the R measurement results. Furthermore, in comparing with results of other experiments it is indicated that the values of resistance obtained in early life may be low while later in life as the RC values become generally higher the measured resistance may be considered to be more mearly the true value. These observations follow from a consideration of the calibration data obtained on the test set for short time constant interfaces.

3. Field Intensity.

The effect of electric field intensity is shown by curves b and c in the group comparing cathode current. There is no difference between curves b and c which is consistent throughout the group and the differences which do exist are insignificant in the light of the wide variation of individual tube section curves. Therefore the results of this experiment indicate no variation of interface growth caused by differences in field intensity at the cathode.

4. Operating Cathode Current.

The effect of cathode current density seems to be quite small. In the case of the 7.5V Eh. tubes the values are generally small and therefore evaluation is somewhat questionable; however the tendency is for greater interface resistance growth in those cathodes operating with current than those operating cut-off and, further, the low current operation appears to be more detrimental than either cut-off or "normal" current operation.

In the case of the 10V. Eh. tubes it should be recalled that the "a" or normal current tubes must be considered as lost and the "3a" curves disregarded because of having operated in a run-away condition. Examination of the operating current comparison group of curves shows a faster interface growth in the low current tubes than in the cut-off tubes in the case of tubes having had no "previous life" other than the standard stabilization period and a tendency toward less rapid initial growth in the low current tubes than in the cut-off tubes as the age under "previous life" operation becomes greater. Generally then, the effect of current on interface growth seems to go from a retarding influence at normal temperatures, as noted by previous investigations through a region where there is very little noticable effect, as suggested in Project Whirlwind Report R-179 section 3.2 and section 3.7, and then into a region where a small amount of current causes a more rapid growth of interface resistance than cut-off operation. This latter effect appears to be tempered by an ageing period under "normal" current and in the case of this experiment elevated cathode temperature 7.5V. Eh.

5. Operating Cathode Temperature.

The effect of operating temperature may be summed up as follows: With operation at 7.5V. Eh the period before

measurable interface impedance is encountered is between 500 and 600 hours. For purposes of comparison a five ohm interface resistance was considered as this measurable level. Operation at 10V. Eh produced measurable interface impedance in periods of 60 hours or less. The rate of interface resistance growth in the 10V. Eh tubes is in the vicinity of $\frac{1}{2}$ ohm per hour. In the 7.5V. Eh tubes the interface resistance growth rate is of the order of 1/40 ohm per hour. These values are mean values over periods of time after the initial growth is established. Individual values range rather widely on both sides of these numbers and the variation is governed by "previous life" operating time such that the longer the "previous life" the faster the initial growth and the earlier the presence of interface is detected. For purposes of this comparison the values obtained at the 4.8V. Eh test condition were used.

6. Cathode Temperature During Measurement.

The effect of cathode temperature during measurement can be determined by examination of the temperature comparison curves. The resistance measured at 100 hours in the 10V. Eh tubes ranged from four to five times larger when measured at 4.8V. Eh than when measured at 5.8V. Eh. However at 600 hours this value was only two to three times higher in the 4.8V. Eh measurement condition with the factor three applying to those tubes having had "previous life"

operation and the "two" applying to those having had no "previous life".

7. Previous Life.

The effect of "previous life" is to show earlier and faster interface resistance growth in the case of the tubes having had the longer "previous life" before entering the special life operation. This also applies to the "previous life" represented by the standard 13 minute stabilization period which is the only "previous life" experienced by the "B" group. Following the initial growth there is a period between 100 and 200 hours when all four "previous life" groups tend to arrive at a common value. This shows as a plateau or a humped region in the case of the longer "previous life" tubes. Beyond this region the tendency is to resume a spread similar to that before the common value region. Only the "A" group, having had no "previous life", shows no plateau, however there is a noticible tendency toward a decrease in growth rate in the "A" group as 600 hours is approached. It is likely that this same plateau effect, as noted in the other groups, would also be found in the "A" group to some extent in the region beyond 600 hours. This would serve further to bring this group down to the expected lower range of resistance values in later life, especially since the slopes decrease quite noticably following the plateau regions noted.

8. Curve Interpretation.

As an aid in examining the curves the following general growth rates are pointed out. A 45° line from the origin is one ohm/hour. A 45° line in the upper left corner is approximately 20 ohms/hour. A 45° line in the upper right corner is approximately 1.4 ohms/hour. and a 45° line in the lower right corner is approximately 1/20 ohm/hour.

9. Temperature Measurements.

The pyrometer measurements show higher operating temperatures in those tubes operating under the "normal" current condition with 7.5V. Eh than in the other tubes operating with 7.5V. Eh. This may be partially a result of meter calibration differences on the two shelves since the "normal" current tubes were alone on a shelf and so had a different heater source. However the fact that the low current tubes operated approximately 10 degrees above the cut-off tubes on the same shelf may be taken to indicate that the heavier current flow in the "normal" current tubes is at least partially responsible for the 40 some degrees temperature difference between cut-off and "normal" current operation. This tendency was not found in the case of the 10V. Eh tubes. However this data is open to some criticism since in each of the four operating groups under 10V. Eh there were one or more tubes which had been retired because of failure involving cathode deterioration. However the overall averages in both the 7.5V. Eh and 10V. Eh groups are considered representative of the

operating temperatures during the special life period. It must be remembered that these temperatures are optical temperatures of the cathode surfaces and must be corrected for emissivity and transmission of path before they are accurate. Assuming an emissivity-transmission of path product of 0.3 the correction is from $+60^{\circ}C$ to $+90^{\circ}C$ for the temperatures measured. This brings the 7.5V. Eh temperature to approximately $825^{\circ}C$ and the 10V. Eh temperature to approximately $990^{\circ}C$. The temperature at 6.3V. Eh is too low to measure using an optical pyrometer so a value for this operating temperature is not available. The program of building tubes with thermocouples which is now in progress should provide much better information on the temperature under various operating conditions.

10. Summary and Discussion.

Reviewing these effects, the outstanding causes for variation in interface growth at these elevated temperatures are operating temperature and previous life experience with operating current playing a less important part, and field intensity having no appreciable effect. However the more rapid development of interface resistance under low current operation than under cut-off operation is a very interesting phenomenon and bears further investigation. The program of building special tubes equipped with thermocouples for operation at various temperatures and currents and for

comparison of various alloys used in the sleeve should provide further information on this phenomenon. Possibly the additional heating in the cathode due to the I^2R losses in the cathode could account for the faster growth at low currents while at higher currents this local heating may be offset to some extent by the increased activation resulting from the current flow. This might account for the more detrimental effect of low current than of cut-off or high current.

The effect of operating temperature on the interface growth is much as expected and as predicted by theory and by previous experiments in the field; higher temperature causes earlier interface appearance and faster growth. The effect of measuring temperature was also much as expected. As in the case of semi-conductors, such as the interface has been shown to be, a reduction of temperature results in an increase in resistivity. The decrease in this order of difference as life is extended suggests a transition of the interface material from semi-conductor toward non-conductor properties. The fact that the greater difference is associated with those tubes having had "previous life" experience suggests that those tubes operating under 7.5V. Eh developed thicker interface layers before entering into the special life operation and that the deactivation at high temperature requires more time than in the case of those tubes having had no appreciable "previous life" and

so having thinner interfaces which would be expected to be deactivated in a shorter period of time.

This deactivation is suggested by the generally accepted model of interface which describes an impurity-activated semi-conductor with the donors being excess barium within the crystal lattice of the semi-conductor, and the tendency for this excess barium to diffuse down temperature gradient toward the surface of the coating material and so away from the interface region. The restoration effect of barium ion electrolysis produced by current flow in the cathode must be unable to keep pace with the diffusion down temperature gradient for this process to explain the deactivation suggested. A steep gradient would imply faster deactivation than a shallow one and here again the tube construction with thermocouples could aid in determining if this action occurs. By means of monitoring internal sleeve temperature using the thermocouples and external temperatures by pyrometry it is possible that a variation of temperature difference with time could be interpreted as indicating a change in the gradient across the cathode. By observing this variation at several different temperatures any tendency toward variation in temperature gradient could be related to operating temperature and perhaps also to interface thickness, should the interface material be a major temperature dropping element in the heat path from

sleeve to surface.

The effect of "previous life" operation on interface growth is of considerable interest in that although after 300 hours of operation no interface was measured, the elevation to 10V. Eh produced quite appreciable interface resistances in a very short time compared to the action under special life of tubes having had shorter "previous life" operation or none at all. Although this is quite a reasonable sort of thing to expect, since it took approximately 400 to 500 hours under the "previous life operating conditions of about 8 ma cathode current at 7.5V. Eh to produce a detactable interface, it does show a marked difference in the interface life acceleration following this "previous life" operation and suggests that interface life tests at elevated temperatures following regular life tests would show appreciably greater acceleration than if begun on new tubes.

One aspect of the measuring procedure has not been investigated. This is the tendency for heaters to conduct more current at a given voltage as their age increases. This heats the cathode to a higher temperature and so would cause a decrease in the measured resistance of a semi-conductor material such as the interface compound. To what extent this might be significant in producing the results obtained in this work is not known since for all

measurements the heater voltage was carefully controlled but heater current was not measured. The further investigation conducted in this project should take note of this possible source of information and loss of control.

11. The 1000 Hour Life Tubes.

In examining the group of tubes received with 1000 hours and then operated on the special 30 tube shelf it is very interesting to note that the earliest and fastest interface development was accomplished by the tubes having had life test operation under ØIp conditions and that the cut-off and regular life tubes both showed lower values of interface resistance. These results seem to bear out previous suggestions that the interface layer forms during previous life and it seems to indicate that it forms to a greater extent in current carrying tubes, possibly because of local heating resulting from I^2R losses in the interface region even though the resistance is not of sufficient magnitude to be measured using present methods. Upon entry into cut-off life and elevated temperature then the magnitude of the resistance is dependent upon the thickness to which the layer has grown to a quite noticable extent. These results serve to further support the practicality of further investigation of interface testing following a period of life test operation and doing the interface life at elevated temperatures.

CHAPTER VI

PHYSICAL EXAMINATION

1. General Observations.

The physical examination phase of the life test program was only slightly touched because of the shortage of time available for work on the project. A few preliminary microscopic examinations were made, primarily to develop some understanding of the problems to be encountered in this part of the work and to investigate techniques to be used in the work. The use of polarized light was investigated and with a crossed analyzer and a 1st order red quarter-wave plate the detail was better than with any other arrangement tried. No low angle lighting was done. Nine photographs were made at 500X magnification on a Metalograph with a nonpolarized light source. These photographs are included in the Appendix. All but one of these photographs are of sections obtained by casting the tube in Castolite then sawing and polishing to reveal the portion of the cathode desired in crossection. The ninth photograph is of a surface from which the coating has been scraped using a piece of paper. No interface was identified and the photographs are of value primarily to indicate the deterioration of cathode coating under high temperature operation.

No chemical or x-ray examinations were performed.

2. Microscopic Examination of a Cathode Surface.

Tube A3c2 which completed 600 hours of special life and developed considerable interface resistance was opened and the cathode was removed from one of the sections. The oxide coating was brushed off with a piece of paper. Examination under polarized light with the analyzer crossed and using a 1st order red quarter-wave plate at 240X showed glassy scale-like formations which seemed to be oriented with and located at the grain boundaries of the nickel sleeve. These scales were quite like those described by Weber [20]. A tool consisting of a sharpened and polished needle rigged to the objective frame of the microscope was used in conjunction with the adjustable stage and the focusing adjustment to lift some of these scales from the cathode surface. This work was done under 200X magnification.

A fine filament of glass was drawn and dipped into warm Canada Balsum. This filament was mounted on the microscope stage and the particles on the needle tip were transferred to the filament. Because the process is a delicate one and because the scales were few in number and widely distributed it was considered impractical further to pursue this procedure in obtaining sufficient sample material for examination by x-ray diffraction methods. If time were available this method is considered quite applicable to the obtaining of a selective sample of microscopic material for analysis by x-ray diffraction methods.

BIBLIOGRAPHY

1. Bartley, W. P. and White, J. E. — Characteristic Shifts in Oxide Cathode Tubes, AIEE Trans. Jan. 1952

2. Child, M. R., A.M.I.E.E. — The Growth and Properties of Cathode Interface Layers in Receiving Valves, The Post Office Electrical Engineers' Journal, Vol. 44, part 4, Jan. 1952, pg. 176

3. Danforth, W. E. and Goldwater, D. L. — J. Applied Phys., Vol. 20, 1949, pg. 163

4. Eaglesfield, C. C. M.A., A.M.I.E.E., and Douglas, M.Sc., A. Inst. P. — British J. Applied Phys., Vol. 2, No. 11, Nov. 1951, pg. 318

5. Eisenstein, A. — J. Applied Phys., Vol. 17, 1946, pg. 434

6. Eisenstein, A. — J. Applied Phys., Vol. 22, 1951, pg. 138

7. Fineman and Eisenstein, A. — J. Applied Phys., Vol. 17, 1946, pg. 663

8. Frost, H. B. — The Vacuum Tube Pulse Current Tester, Eng. Note E-400, Mar. 15, 1951, Project Whirlwind

9. Frost, H. B. — Cathode Interface Impedance and It's Effects in Aged Vacuum Tubes, Eng. Note E-395, Project Whirlwind

10. Hermann, Dr. Ing. G. and Wagener, Dr. Phil S. — The Oxide Coated Cathode, Vol. 2, Chapman & Hall Ltd. 1951, pg. 276

11. Matheson, R. M., and Nergaard, Leon S. — High Speed Ten Volt Effect, R.C.A. Industry Service Rept. LB. 833, May 25, 1951

12. Matheson, R. M. and Nergaard, Leon S. — A Bridge for the Measurement of Cathode Impedance, R.C.A. Laboratories Bulletin LB. 945, May 11, 1954

13. Matheson, R. M. and Nergaard, Leon S. — Studies of the Interface Layer in Oxide Cathodes, R.C.A. Laboratories Bulletin LB. 944, May 11, 1954

14. Nergaard, L. S. — Studies of the Oxide Cathode R.C.A. Review, Vol XIII Dec. 1952, pg. 464

15. Rooksby, H. P. — Nature, (Paris, France) Vol. 159, 1947, pg. 609

16. Tillman, W. F. — Investigation of Sine Wave Method of Cathode Interface Measurement, Test Lab, G.E. Owensboro, Ky. Feb. 3, 1955

17. van der Ziel, A. — Study of the Cause and Effect of Flicker Noise in Vacuum Tubes 2nd Qtrly. Rpt., Electron Tube Research Laboratory, U. of Minn. Dec. 15, 1953 - Mar. 15, 1954

18. Wagner, H. M. — Cathode Interface Impedance and It's Measurement, Prod. National Electronics Conference 1952, Vol. 8

19. Waymouth, J. F., Jr. — Deterioration of Oxide-Coated Cathodes under Low Duty - Factor Operation, J. Applied Phys. Vol. 22, 1951, pg. 80

20. Weber, A. P. — Investigation of Oxide Cathodes with Interface Resistance, Telefunken Zeitung, Vol. 26, No. 99, Mar. 1953, pg. 123

21. Project Whirlwind Summary Reports Nos. 20, 21, 22, 23, 24, 25, 26

22. Project Whirlwind Report R-139 June 1, 1948

23. Project Whirlwind Report R-179 June 29, 1950

24. 6th Qtrly. Rpt. on Contract NObar 57523 May, June, July 1954 Armed Services Technical Information Agency

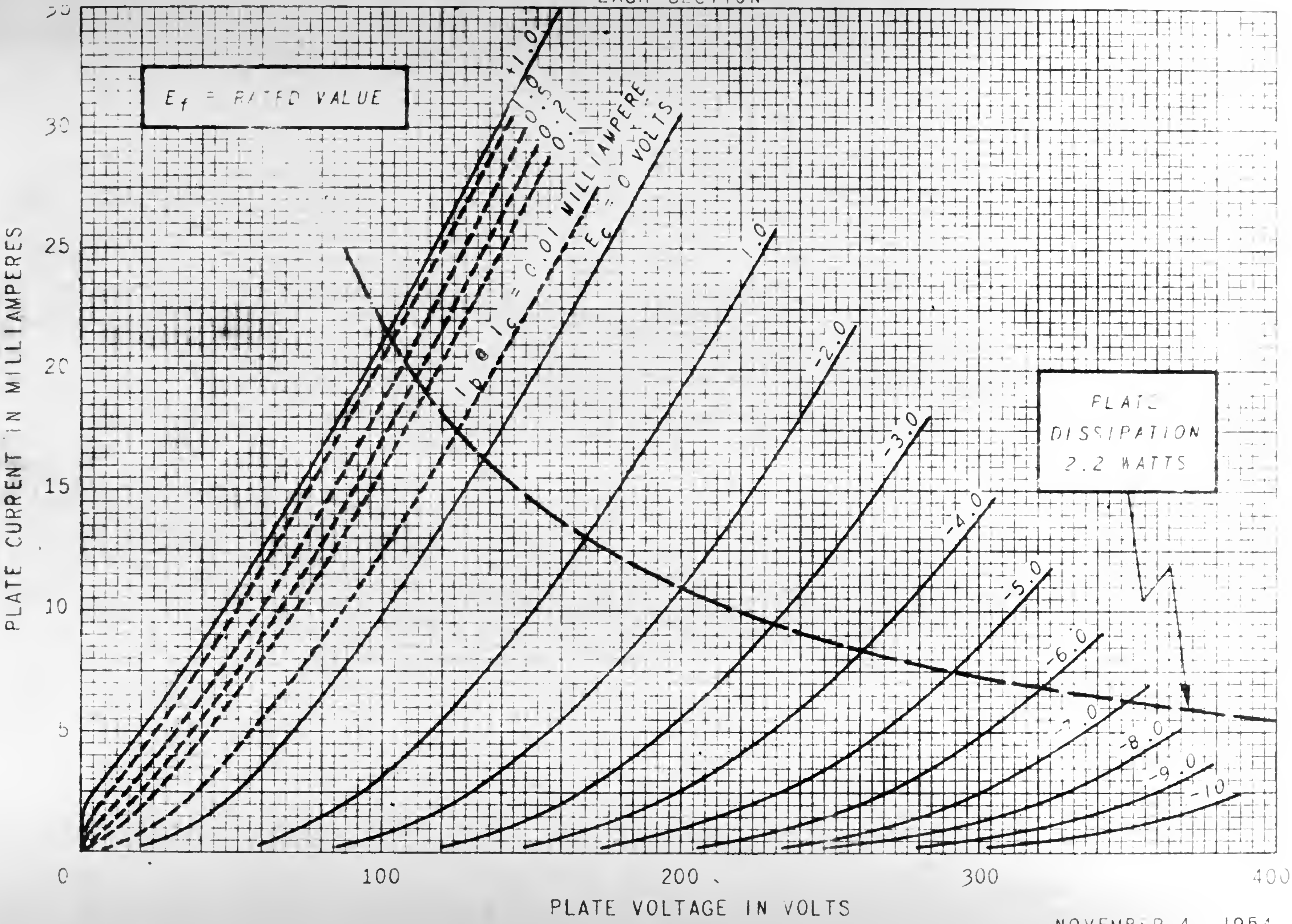
APPENDIX I

TUBE OPERATING CHARACTERISTICS

The following five pages are the published Average Characteristics for the Type Z-2177 (I.B.M. No. 0528).

AVERAGE PLATE CHARACTERISTICS

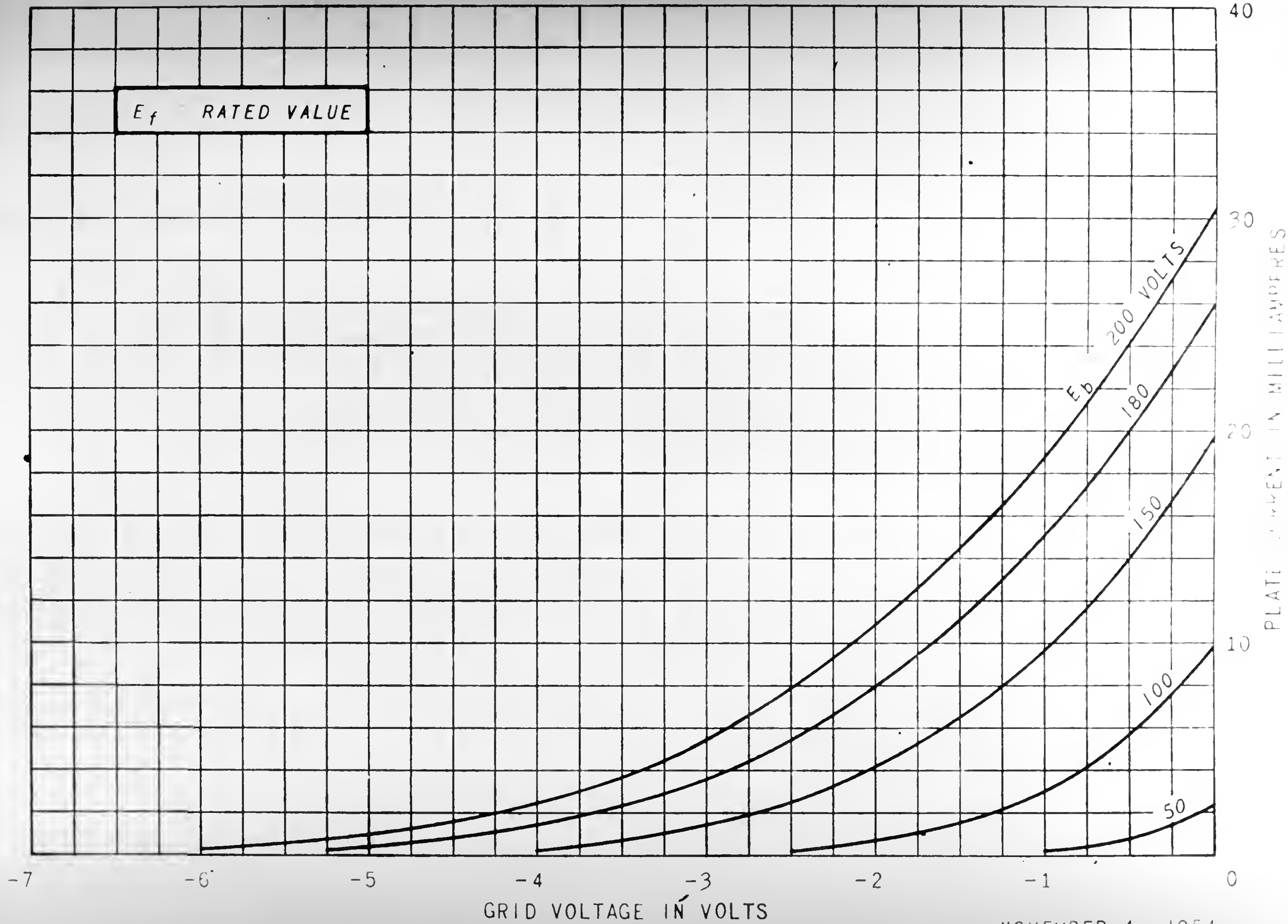
EACH SECTION



NOVEMBER 4, 1954

AVERAGE TRANSFER CHARACTERISTICS

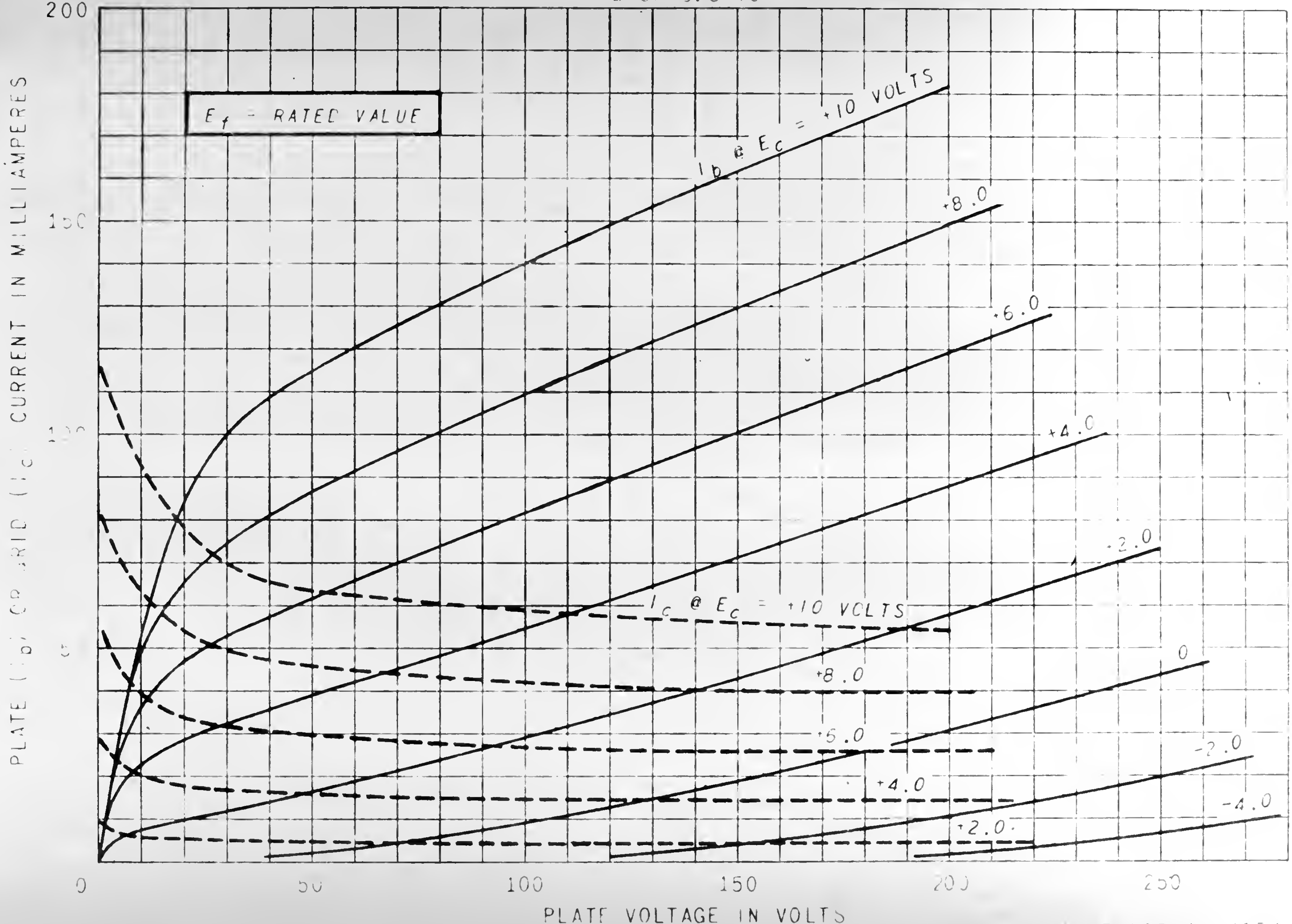
EACH SECTION



NOVEMBER 4, 1954

AVERAGE PLATE CHARACTERISTICS

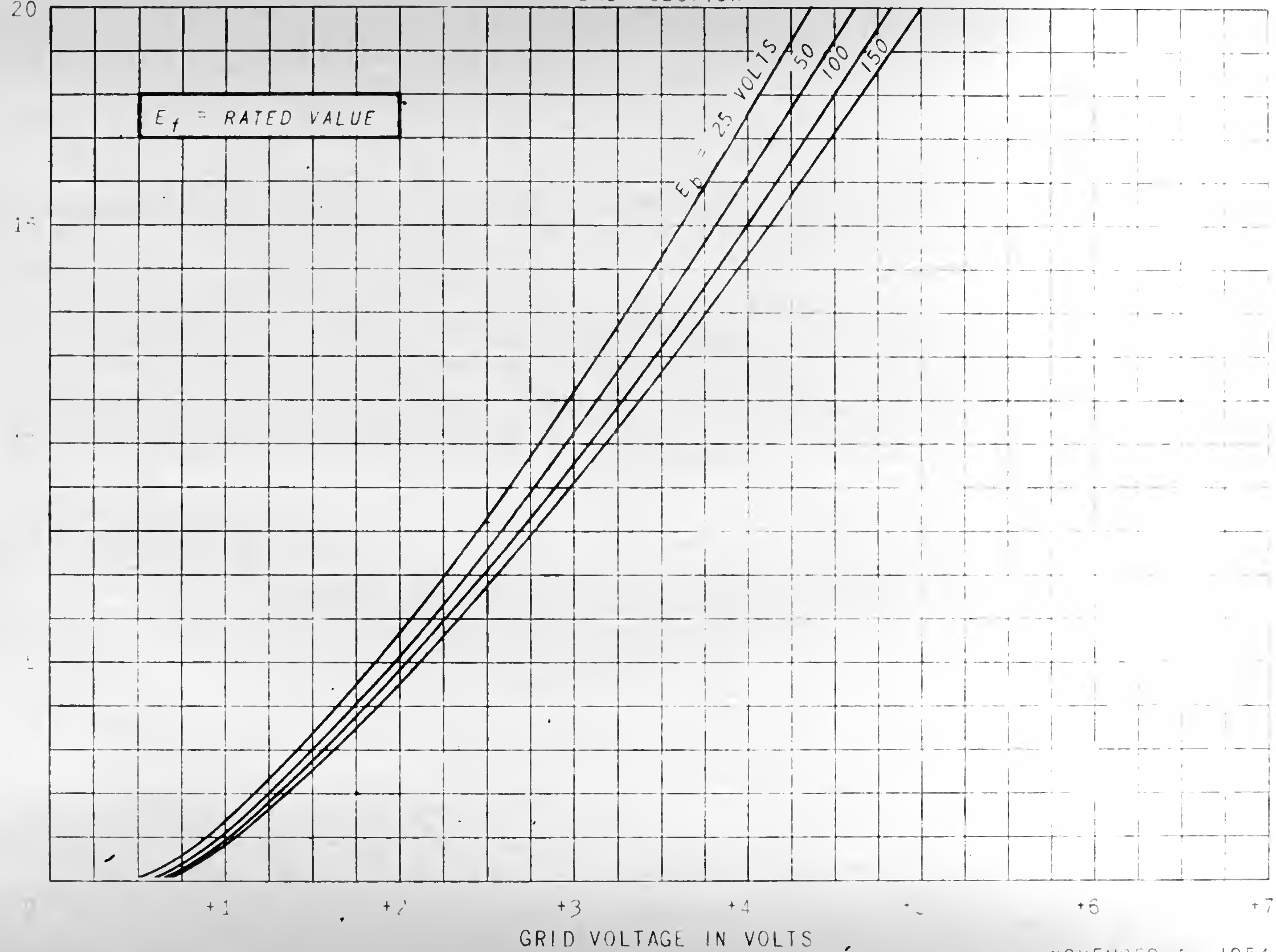
EACH SECTION



NOVEMBER 4, 1954

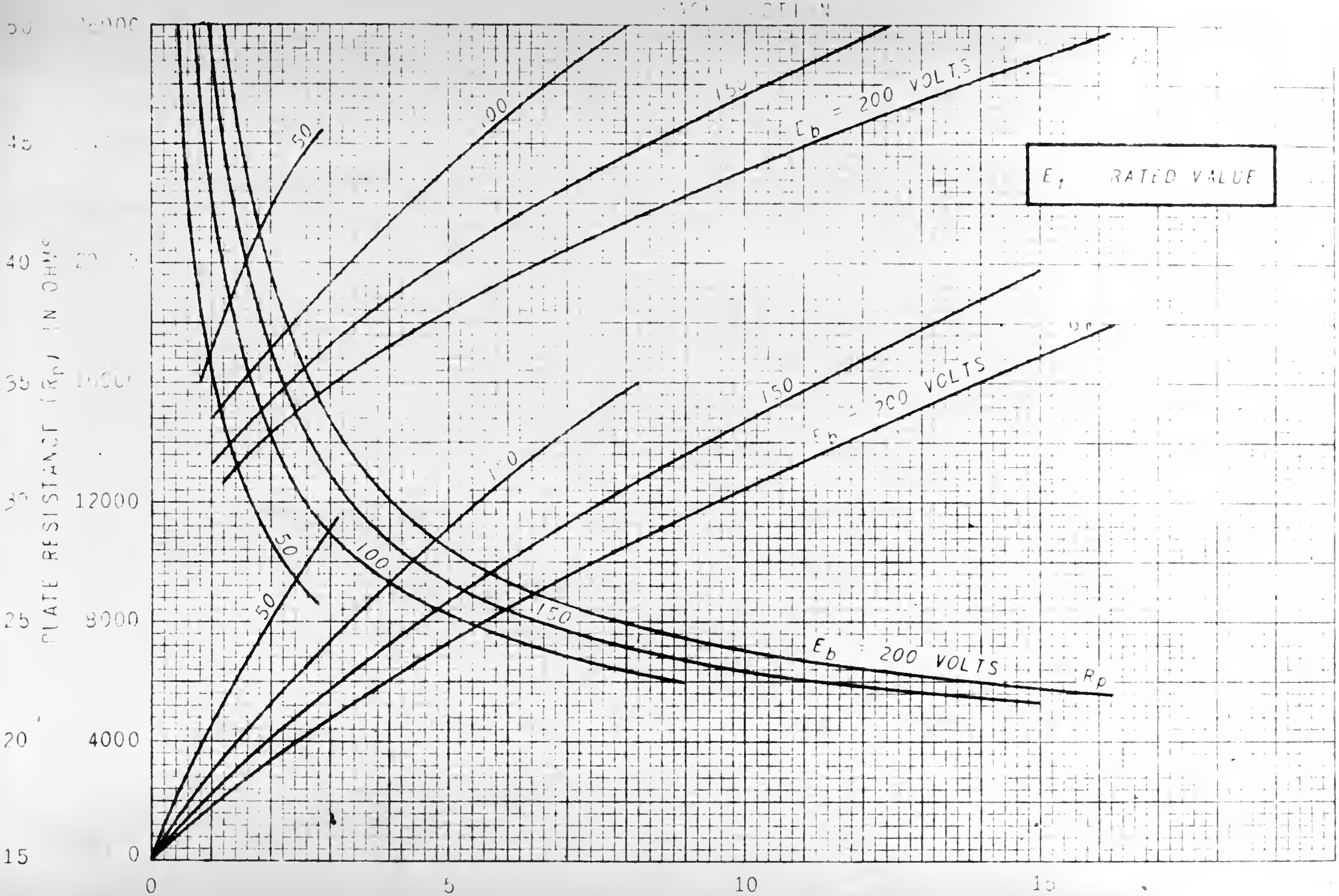
AVERAGE CHARACTERISTICS

EACH SECTION



NOVEMBER 4, 1954

AVERAGE CHARACTERISTICS

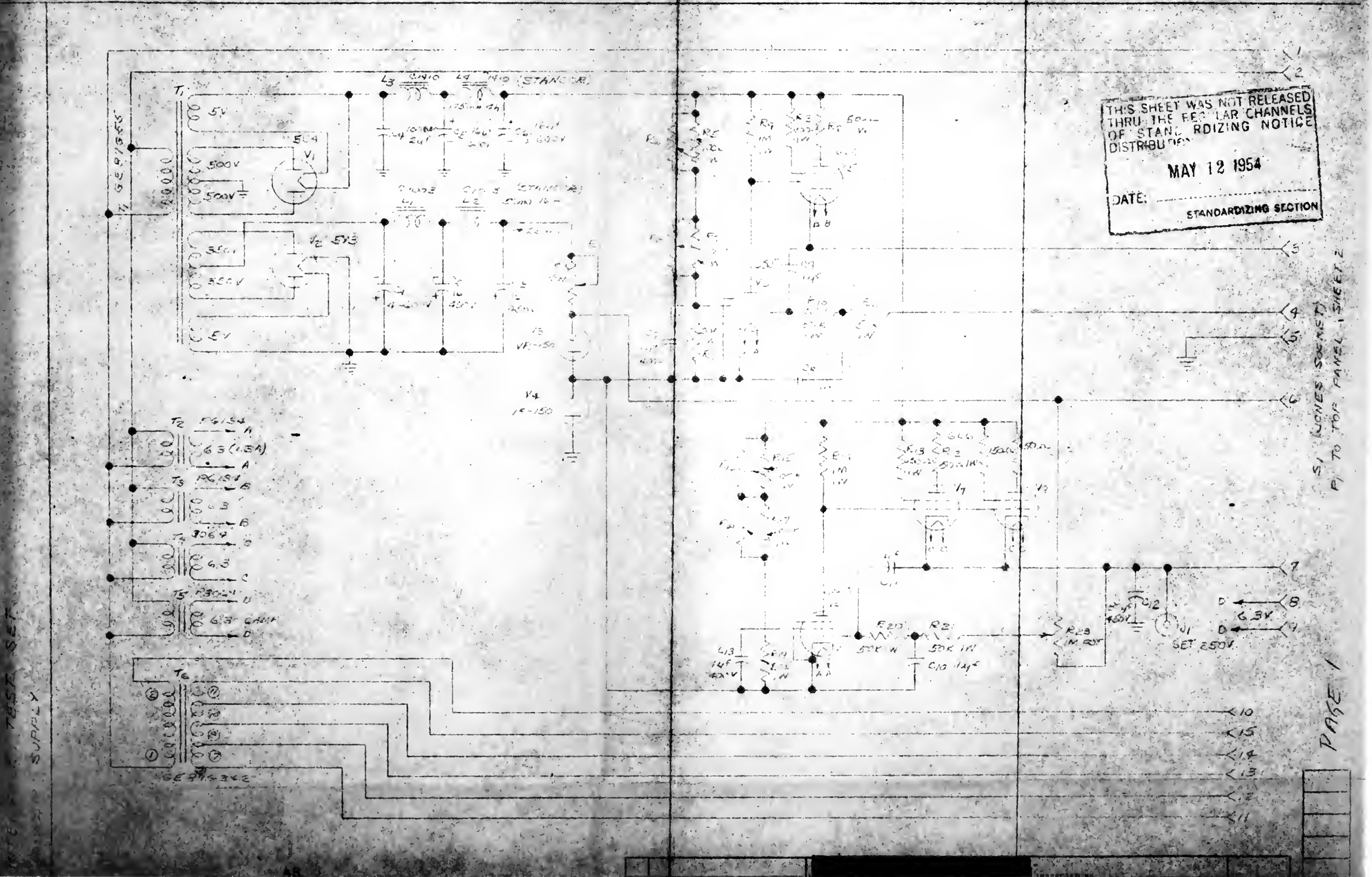


NOVEMBER 4, 1954

APPENDIX II

INTERFACE TEST SET DATA

The following eight pages contain the Interface Test Set Schematics, Square Wave Data, and Short Time Constant Calibration Data.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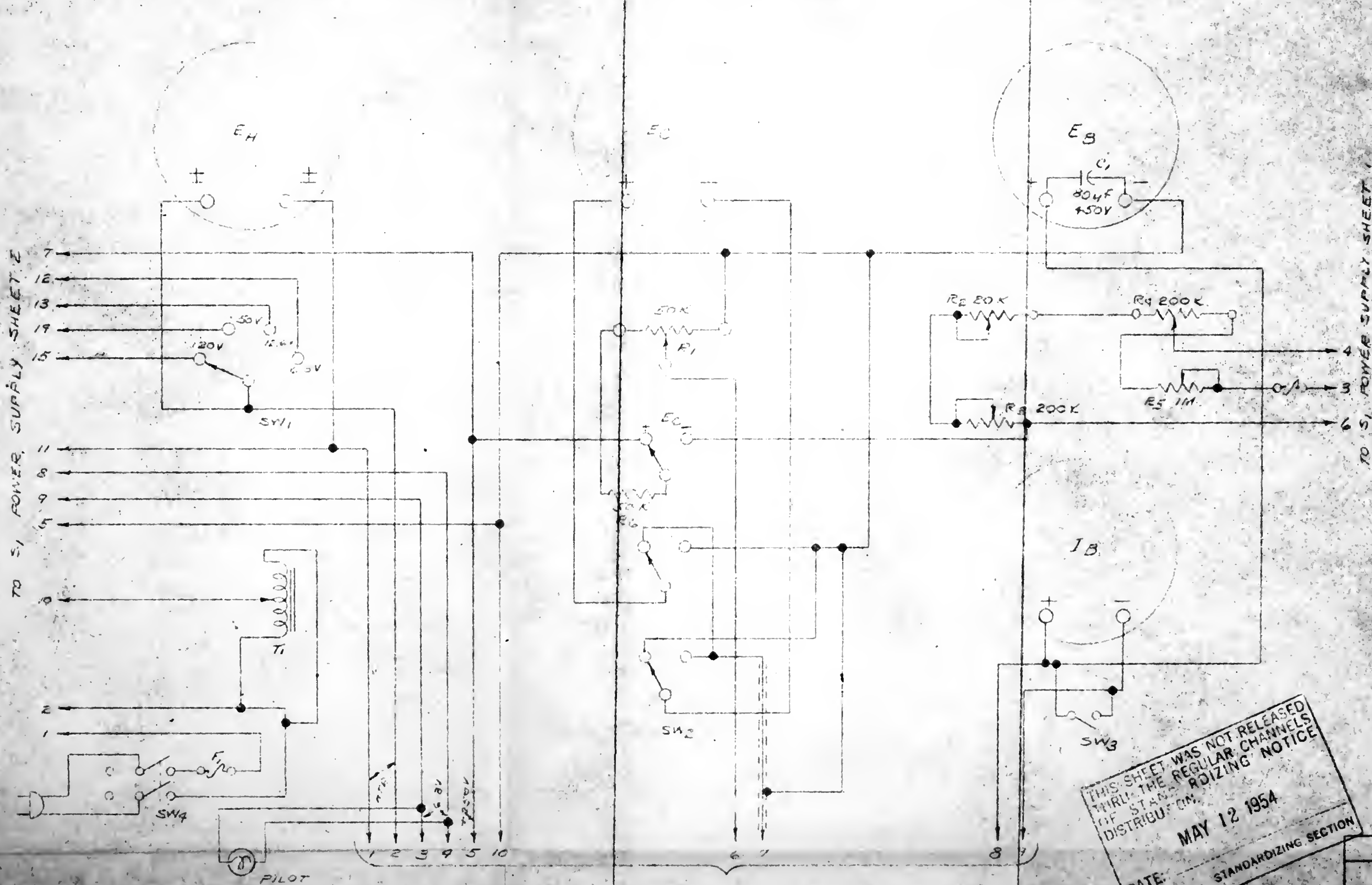
THRU THE REG LAR CHANNELS
OF STAN RDIZING NOTICE
DISTRIBU
MAY 12 1954
DATE:
STANDARDIZING SECTION
SET 250V.
6.3V
S1 (JONES SOCKET)
P1 TO TOP PANEL 1 SHEET 2
PAGE 1
TEST SET
SUPPLY

TOP PANEL BACK VIEW



TOP PANEL BACK VIEW

PAGE 2

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DATE: MAY 12 1954

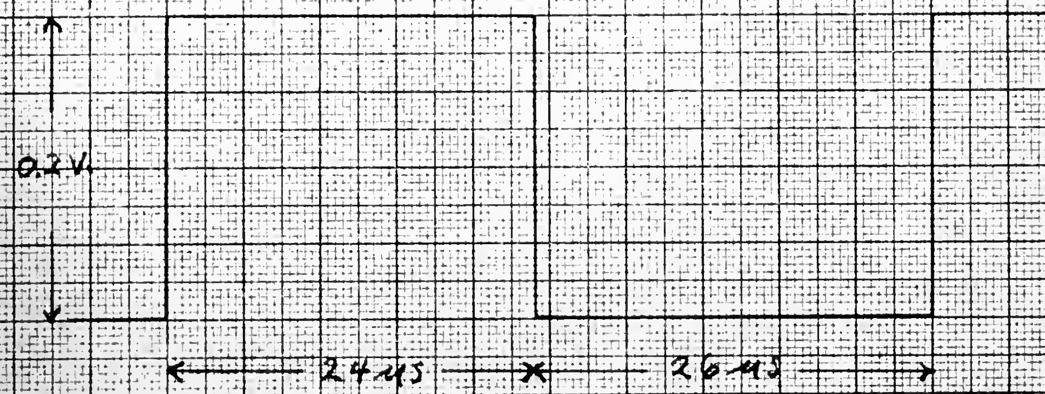
STANDARDIZING SECTION

[redacted] INSPECTED BY

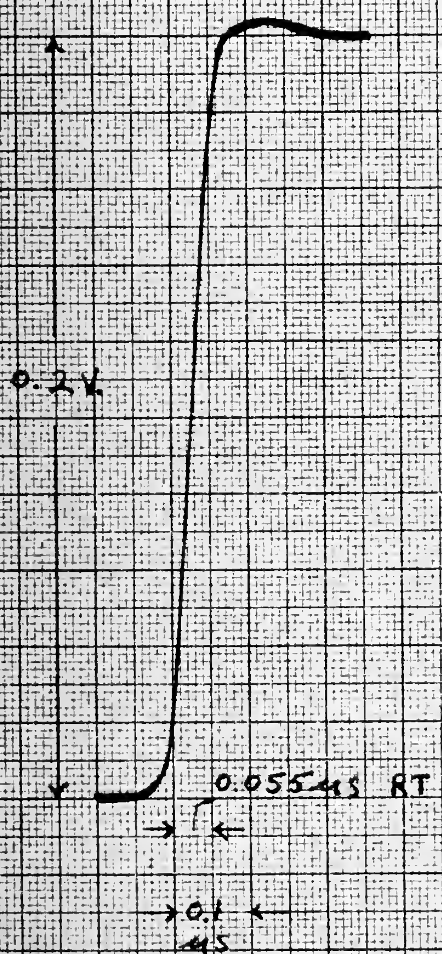
Interface Impedance Test Set
Square Wave Data

3/11/55

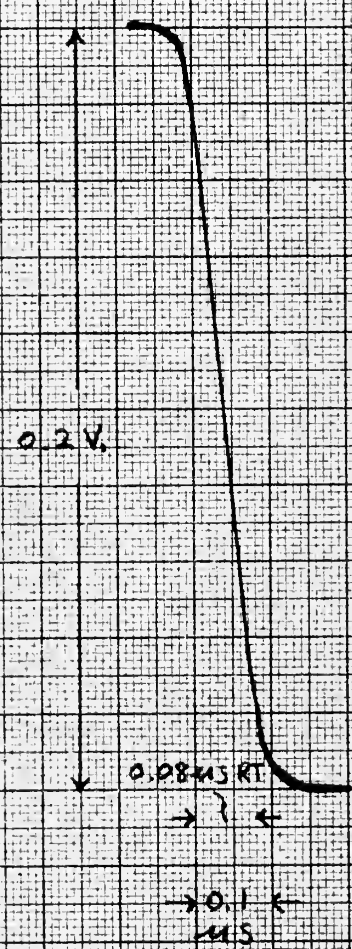
Scope - Tektronix 315D Ser. No. 449



Leading Edge



Trailing Edge



<u>CALIBRATION OF TEST SET - SHORT RC</u>

RC (nominal)	R (Ω)	C (uf)	Value Read R (Ω)	Value Read C (uf)	Top of Null R (Ω)	Top of Null C (uf)
0.01	9.8	0.001	0			
	46.2	0.000214	10	0.0026	21	0.0007
	100.5	0.000099	40	0.0006	148	0.00001 * Dist
	149.2	0.000063	66	0.00028	200	Dist
	214.0	0.000043	111	0.00014	242	Dist
	263.0	0.000039	153	0.0001	290	Dist
0.05	9.8	0.005	4	0.02	6	0.008
	46.2	0.00106	34	0.0019	45	0.001
	100.5	0.000502	92	0.0006	100	0.00049
	149.2	0.000328	135	0.00038	152	0.00027
	214.0	0.00023	196	0.00024	218	0.00017
	263.0	0.000135	246	0.00013	266	0.0001
0.03	9.8	0.003	0			
	46.2	0.00063	21	0.0024	33	0.0009
	100.5	0.000303	69	0.00057	91	0.0003
	149.2	0.000202	113	0.0003	142	0.00016
	214.0	0.000139	171	0.00017	210	0.0001
	263.0	0.000112	224	0.00012	263	0.00007
0.1	9.8	0.0099	8	0.01		
	46.2	0.00225	44	0.0025	48	0.002
	100.5	0.00105	100	0.00106	104	0.001
	149.2	0.000669	147	0.00072	153	0.00063
	214.0	0.00046	212	0.00047	219	0.00045
	265.0	0.000374	262	0.00037	272	0.00033

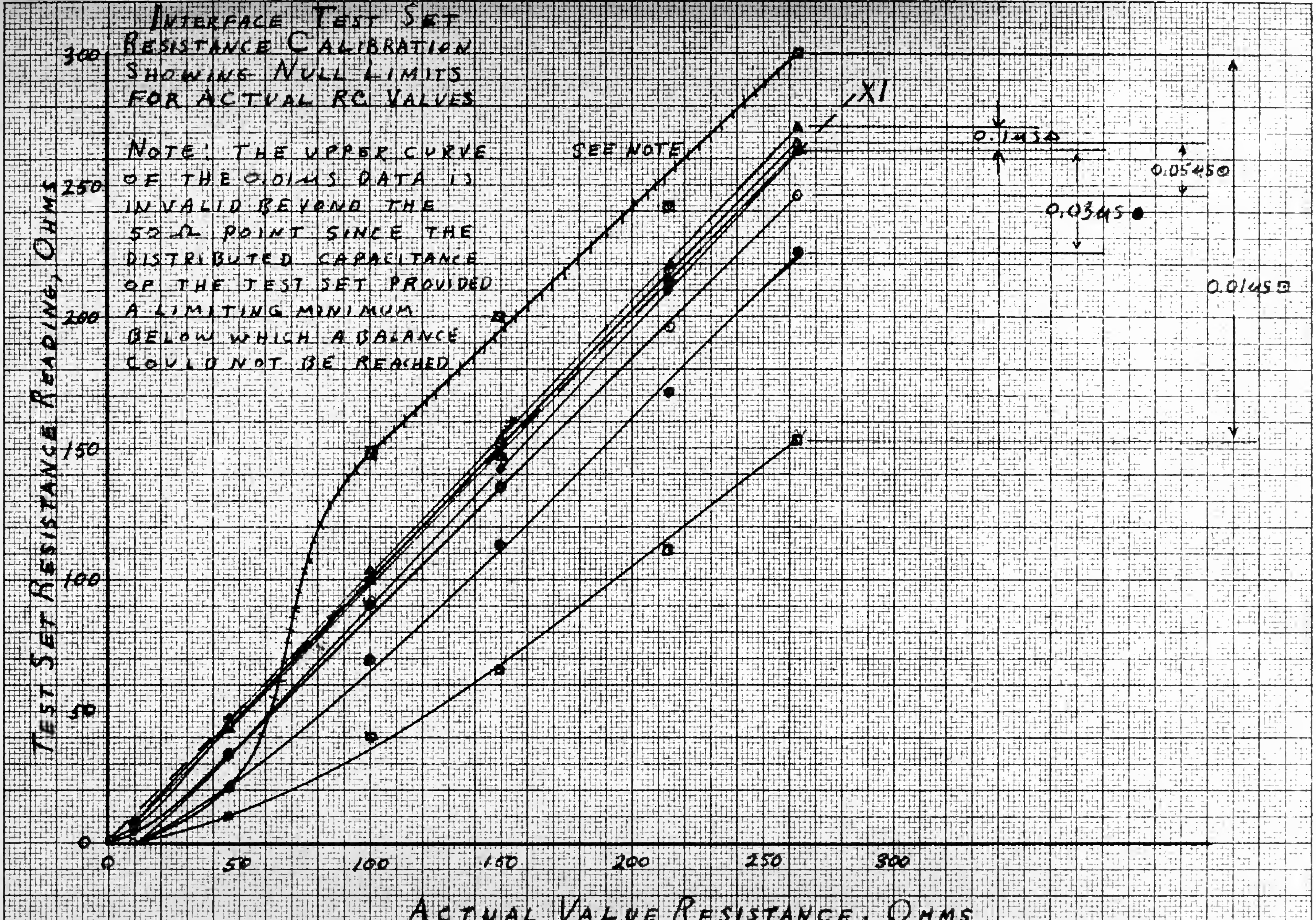

INTERFACE TEST SET
RESISTANCE CALIBRATION
SHOWING NULL LIMITS
FOR ACTUAL RC VALUES
NOTE: THE UPPER CURVE OF THE 0.01µS DATA IS INVALID BEYOND THE 50 Ω POINT SINCE THE DISTRIBUTED CAPACITANCE OF THE TEST SET PROVIDED A LIMITING MINIMUM BELOW WHICH A BALANCE COULD NOT BE REACHED.
SEE NOTE
XI
0.1µS
0.05µS
0.03µS
0.01µS
TEST SET RESISTANCE READING, OHMS
ACTUAL VALUE RESISTANCE, OHMS
0
50
100
150
200
250
300

FIG 1

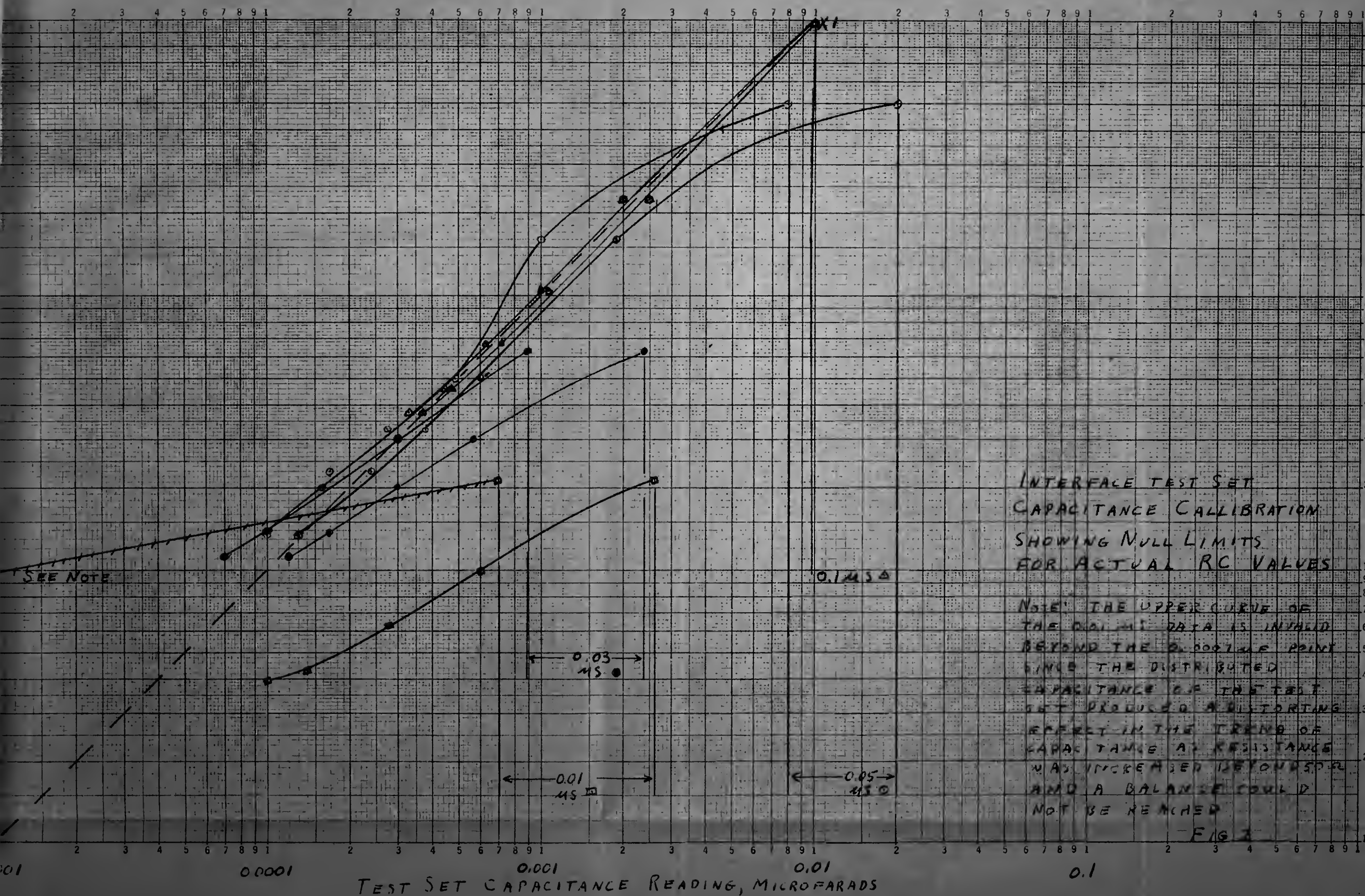
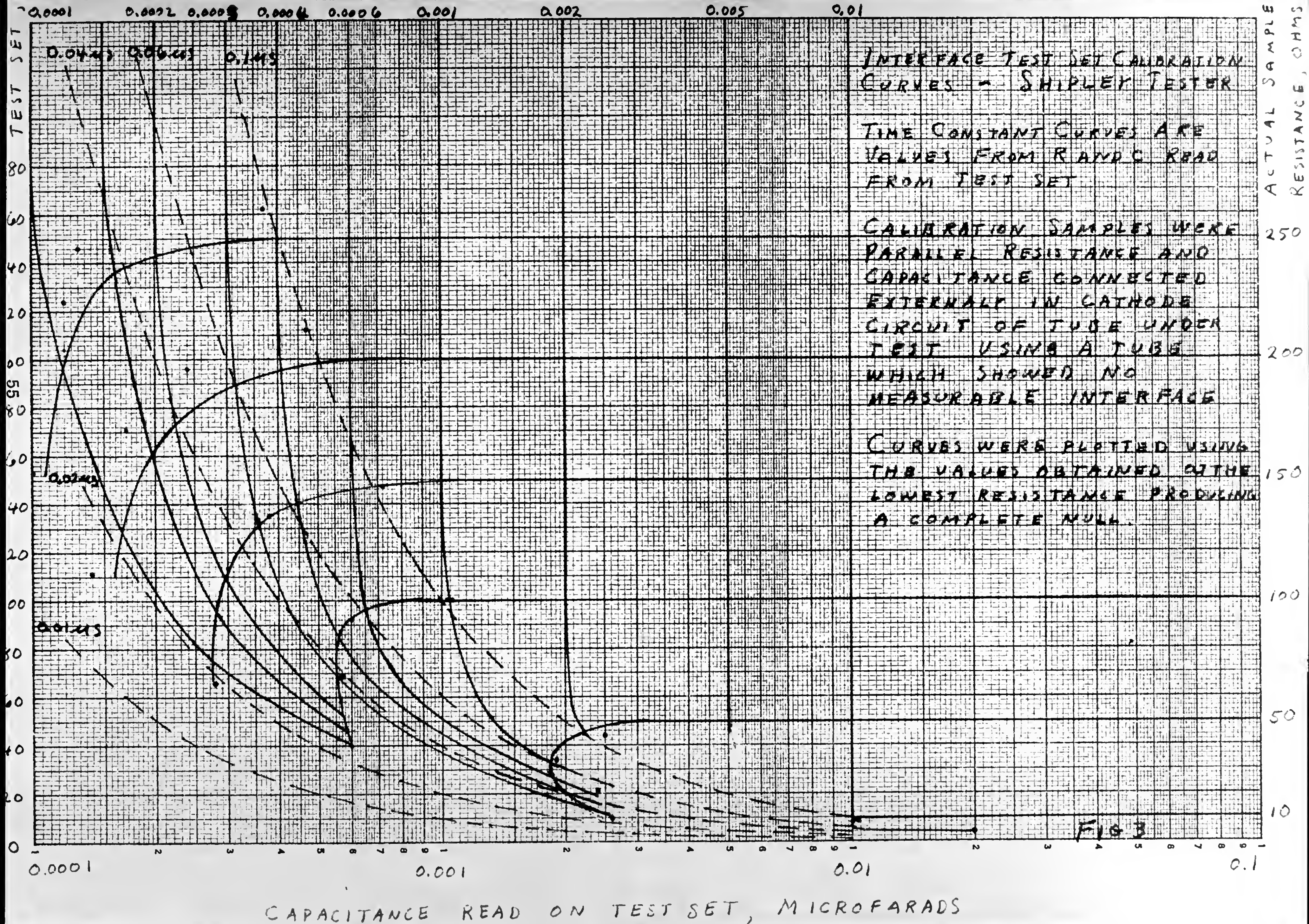

X1
SEE NOTE
0.1 MS △
0.03 MS ●
0.01 MS ⊡
0.05 MS ⊙
.001
0.0001
0.001
0.01
0.1
TEST SET CAPACITANCE READING, MICROFARADS
INTERFACE TEST SET
CAPACITANCE CALLIBRATION
SHOWING NULL LIMITS
FOR ACTUAL RC VALUES
NOTE: THE UPPER CURVE OF
THE 0.01 MS DATA IS INVALID
BEYOND THE 0.0007 μF POINT
SINCE THE DISTRIBUTED
CAPACITANCE OF THE TEST
SET PRODUCED A DISTORTING
EFFECT IN THE TREND OF
CAPACITANCE AS RESISTANCE
WAS INCREASED BEYOND 50 Ω
AND A BALANCE COULD
NOT BE REACHED

FIG 3



INTERFACE TEST SET CALIBRATION CURVES - SHIPLEY TESTER
TIME CONSTANT CURVES ARE VALUES FROM R AND C READ FROM TEST SET
CALIBRATION SAMPLES WERE PARALLEL RESISTANCE AND CAPACITANCE CONNECTED EXTERNALY IN CATHODE CIRCUIT OF TUBE UNDER TEST USING A TUBE WHICH SHOWED NO MEASURABLE INTERFACE
CURVES WERE PLOTTED USING THE VALUES OBTAINED AT THE LOWEST RESISTANCE PRODUCING A COMPLETE NULL.
0.04μs
0.06μs
0.1μs
0.02μs
0.01μs
0.0001
0.0002
0.0003
0.0004
0.0006
0.001
0.002
0.005
0.01
0.1
CAPACITANCE READ ON TEST SET, MICROFARADS
ACTUAL SAMPLE RESISTANCE, OHMS
250
200
150
100
50
10

FIG 3

55

APPENDIX III

CURVES

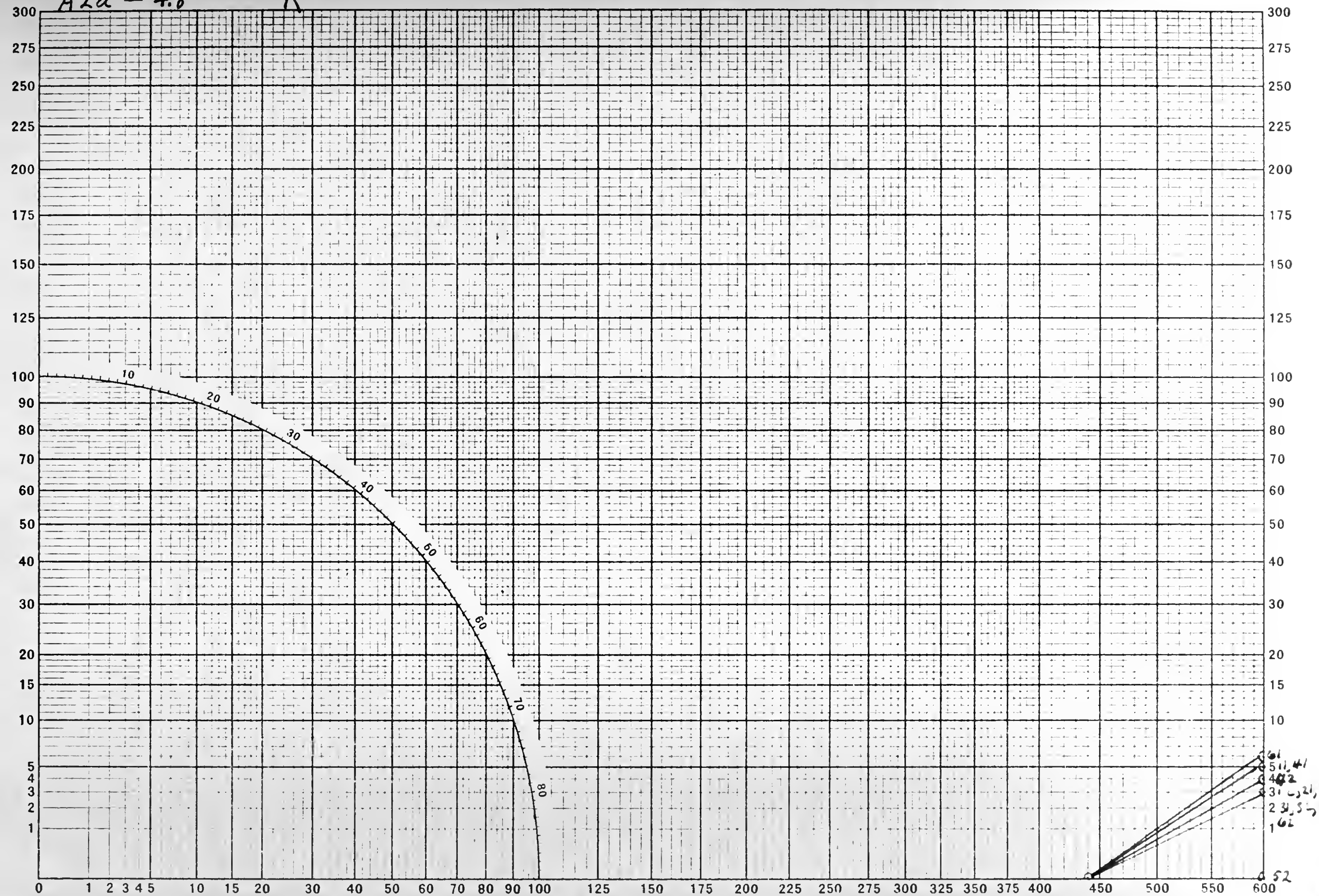
The curves are arranged in groups as follows:-

Following page number:	Subject:
57	Individual Resistance
58	Average Resistance, Single Group
59	Average Resistance, Comparing Field Intensity and Operating Cathode Current Effects
60	Average Resistance, Comparing Operating Cathode Temperature Effects
61	Average Resistance, Comparing Previous Life Experience Effects
62	Average Time Constant, Single Group
63	Average Time Constant, Comparing Field Intensity and Operating Cathode Current Effects
64	Average Time Constant, Comparing Operating Cathode Temperature Effects
65	Average Time Constant, Comparing Previous Life Experience Effects
66	Average Resistance, Comparing Previous Life Experience Effects in the Tubes Received with 1000 Hours Life

INDIVIDUAL RESISTANCE

Full Scale 0 2 3 4 **Individual Standard Errors** **Tenth Scale**

A2a — 4.8 R

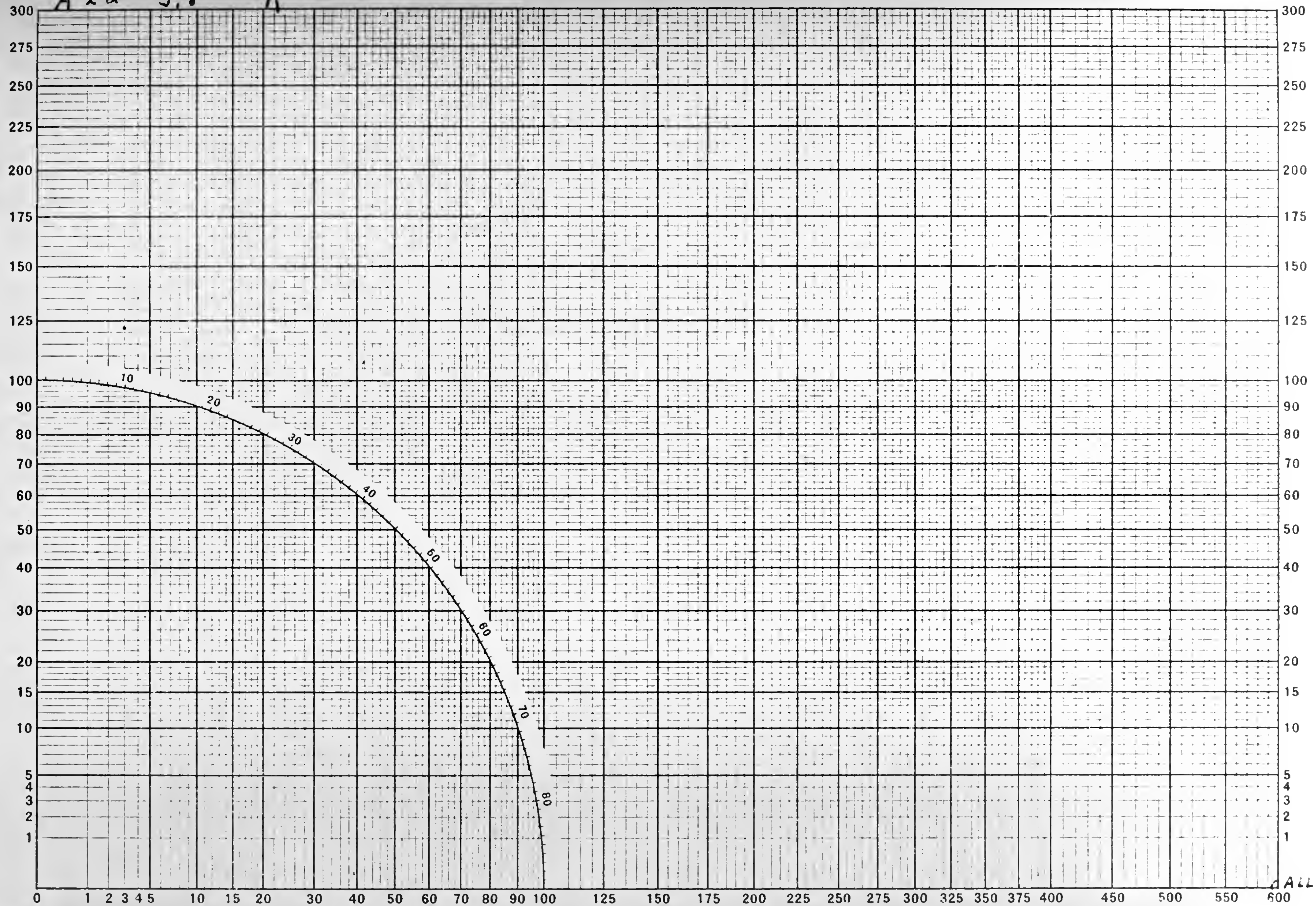


Full Scale

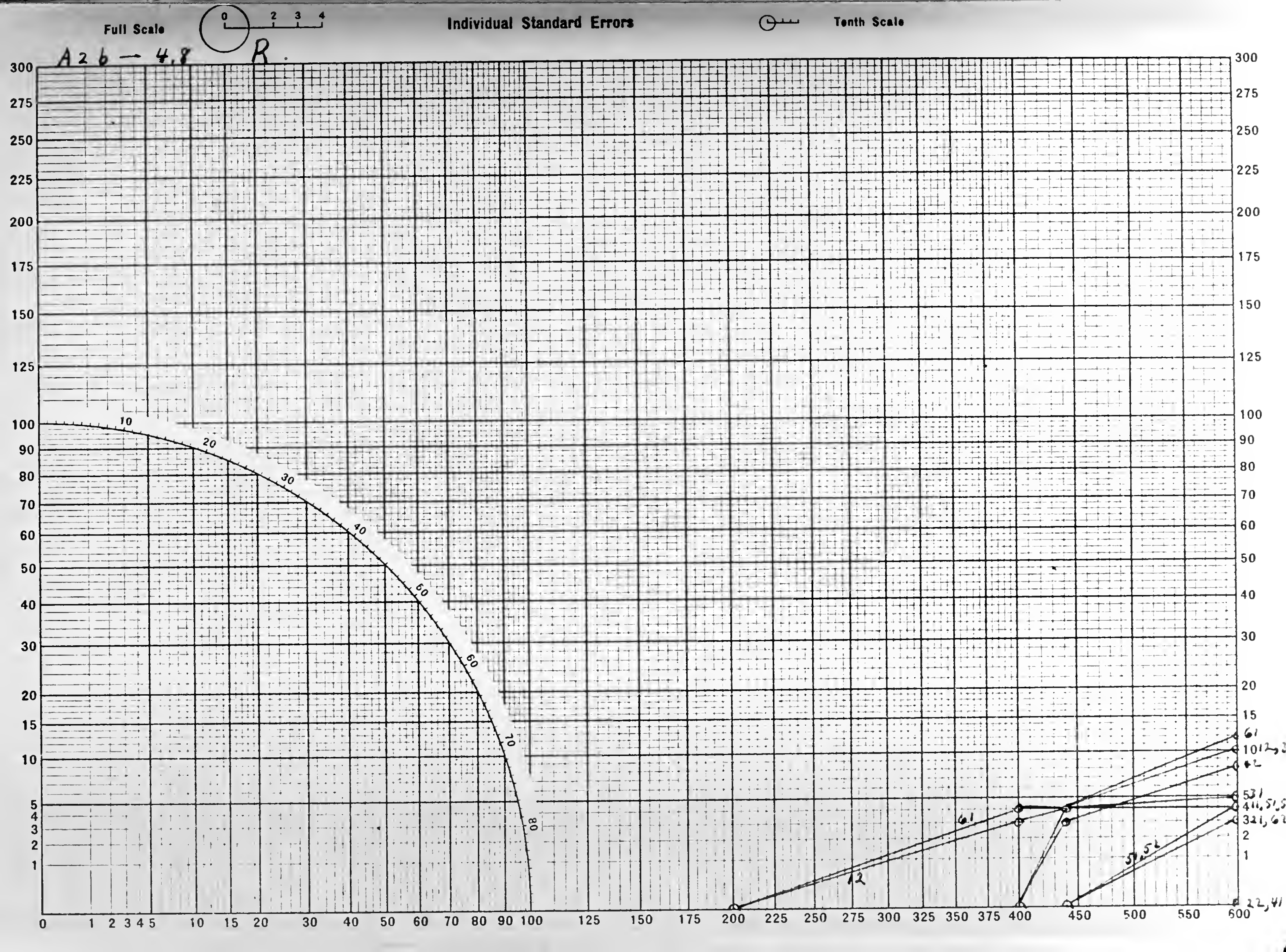
Individual Standard Errors

Tenth Scale

A 2a — 5.8 R



ALL

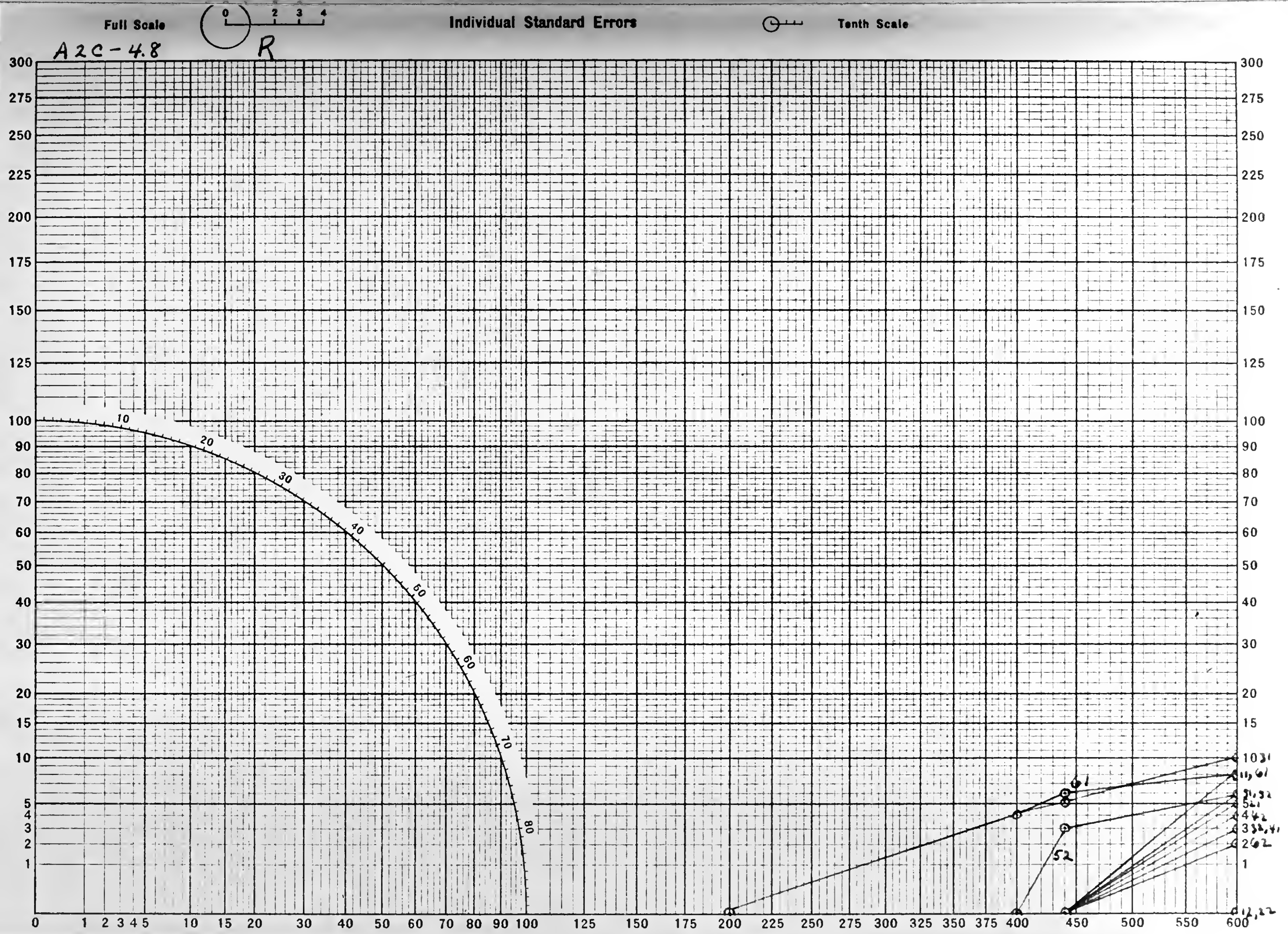

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2 b — 4.8
R
61
12
51, 52
61
1012, 3
62
531
411, 51, 5
321, 62
22, 41

Full Scale

Individual Standard Errors

Tenth Scale

A 2 b — 5.8


Full Scale
Individual Standard Errors
Tenth Scale
A2C-4.8
R
61
52
103
11,61
51,32
521
442
332,41
262
12,22

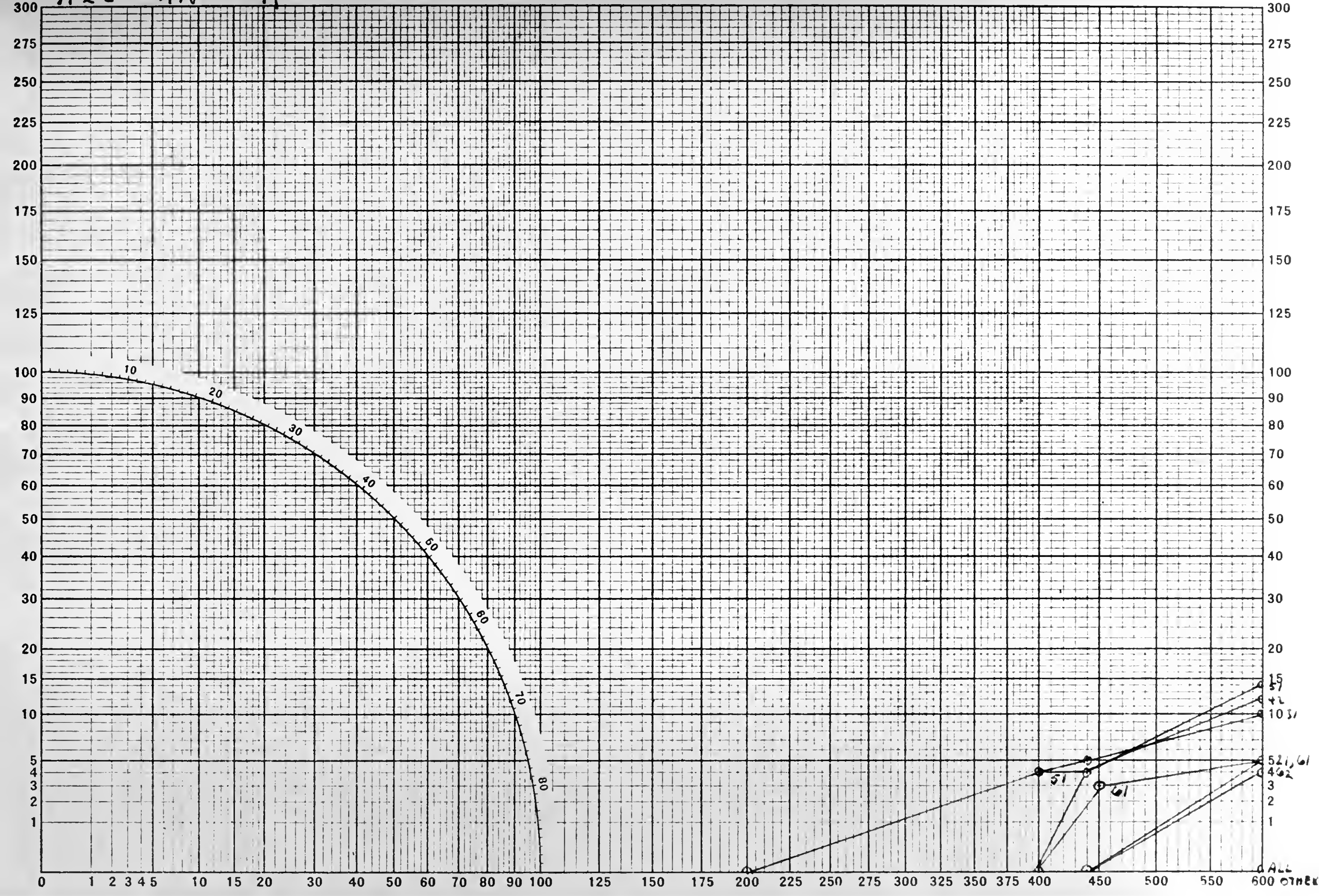
- Full Scale
Individual Standard Errors
Tenth Scale
A 2 C - 5.8
R
61
331,6
ALL OTHE

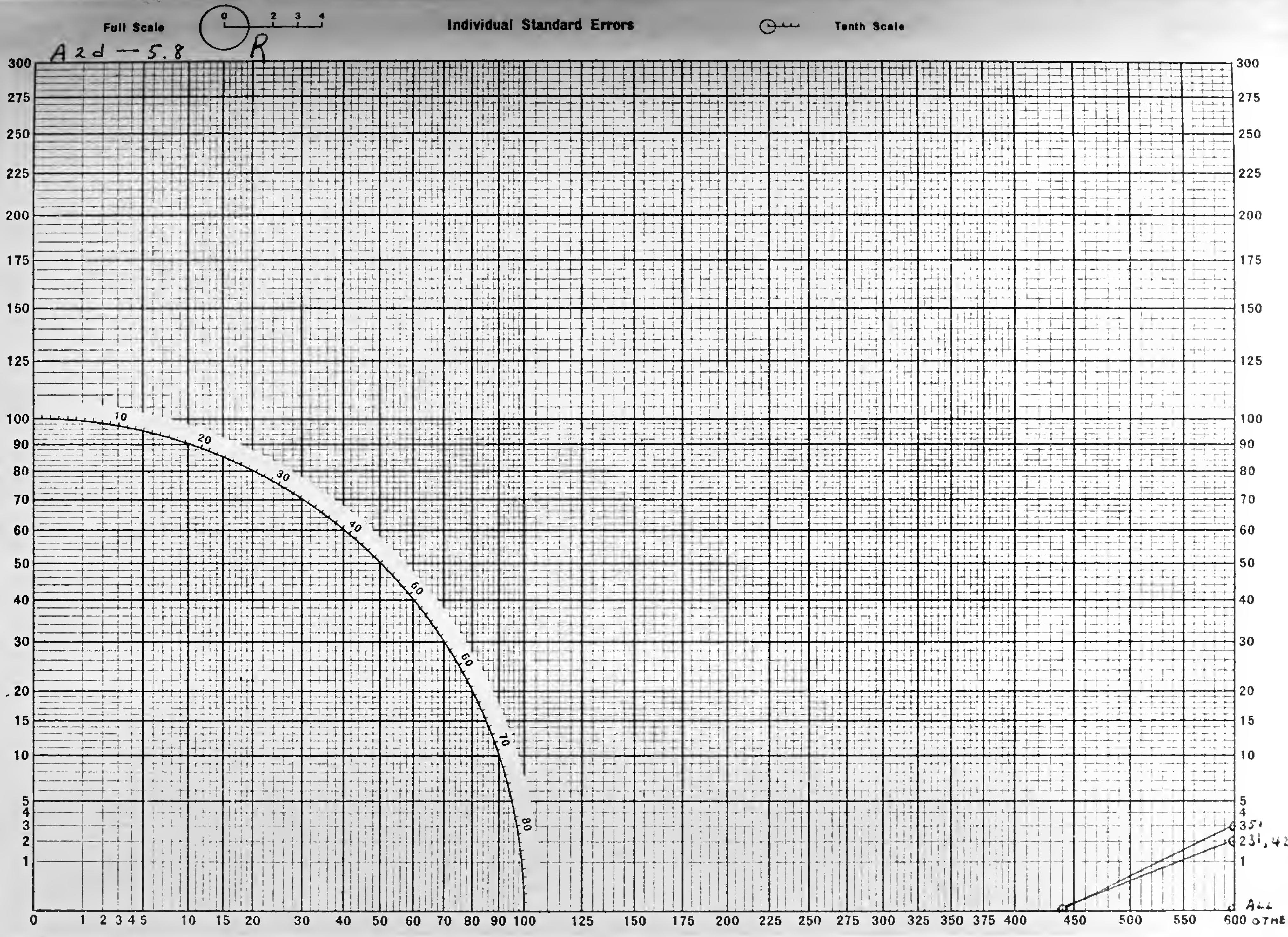
Full Scale

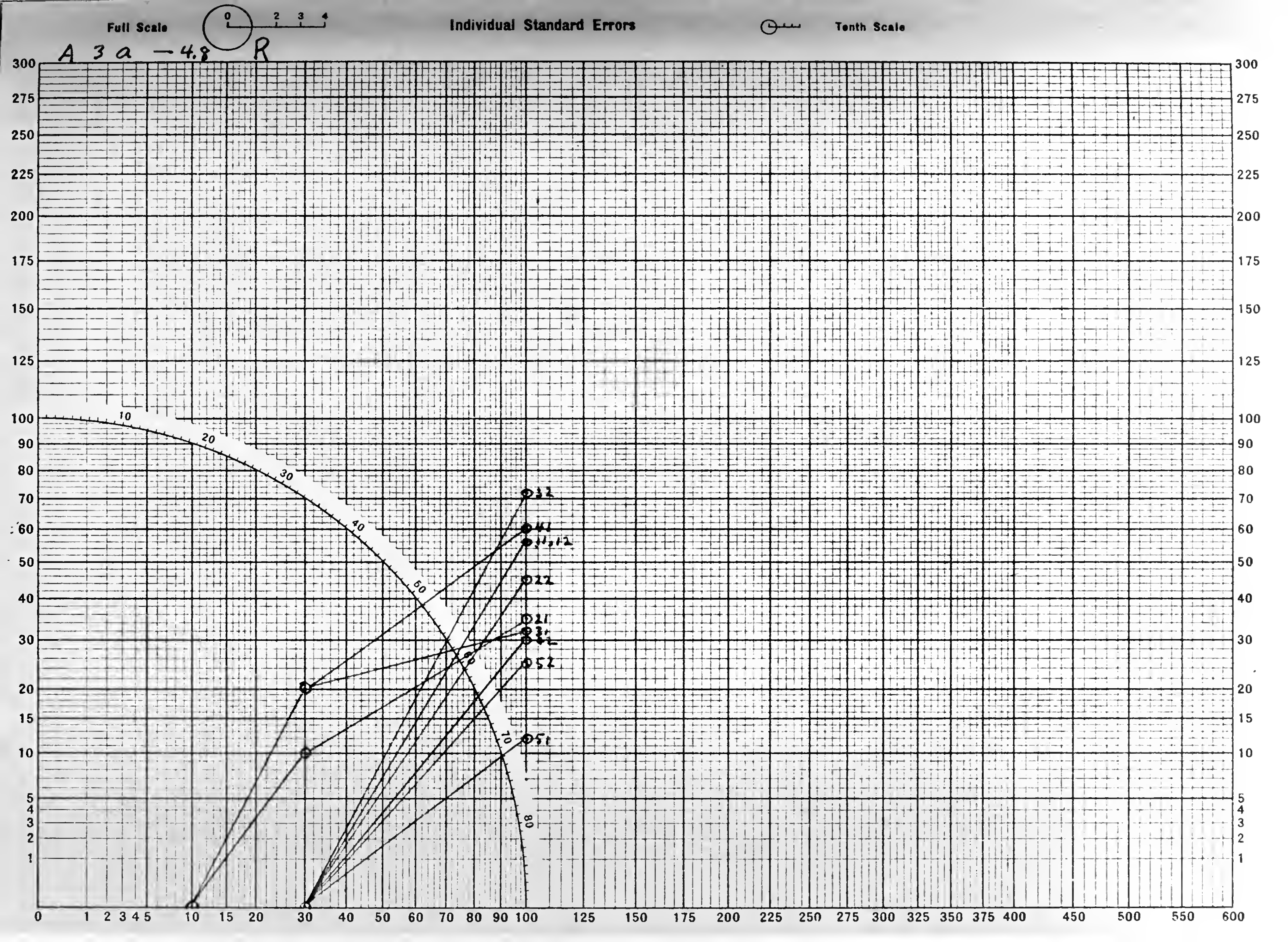
Individual Standard Errors

Tenth Scale

A2d — 4.8 R

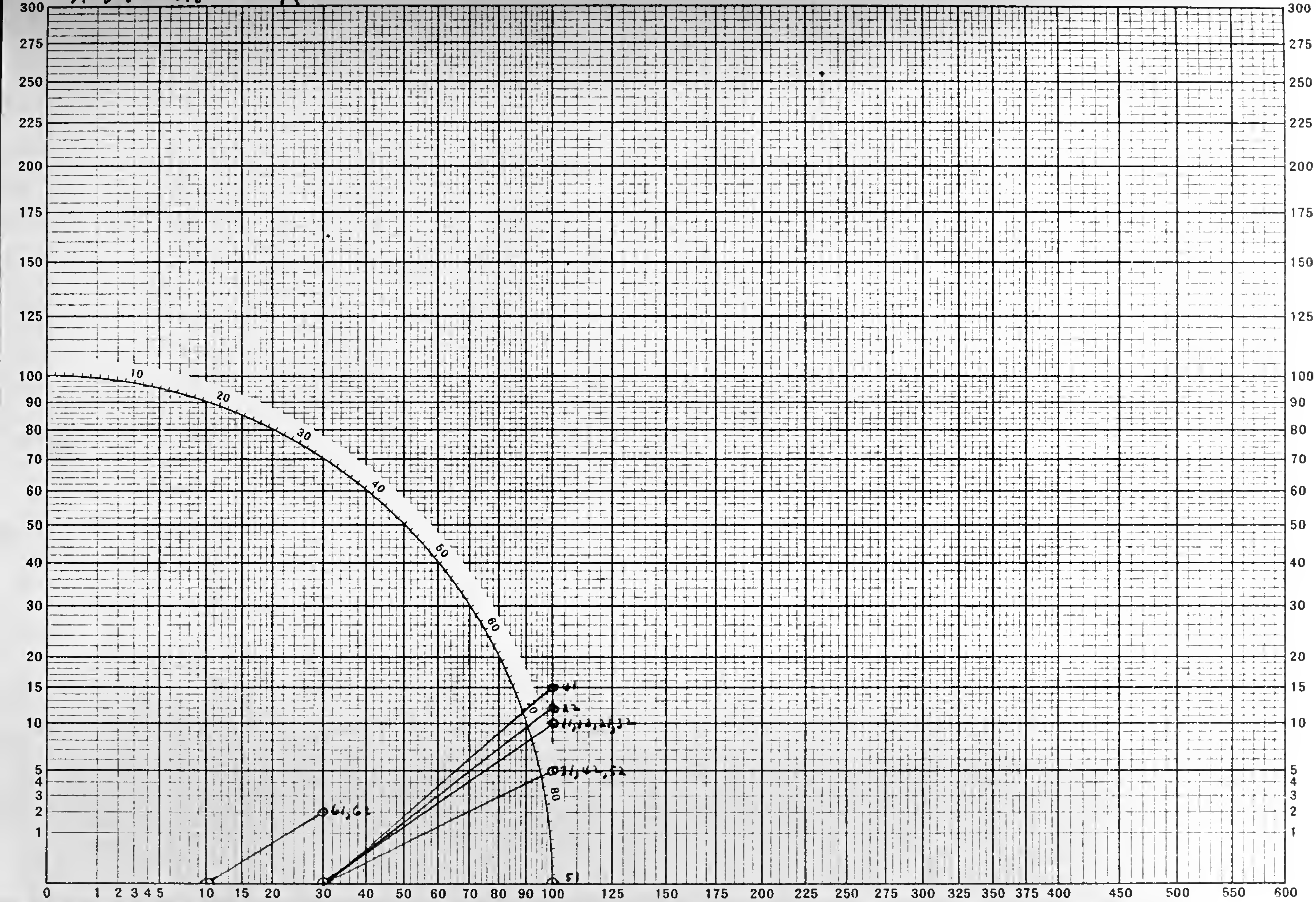


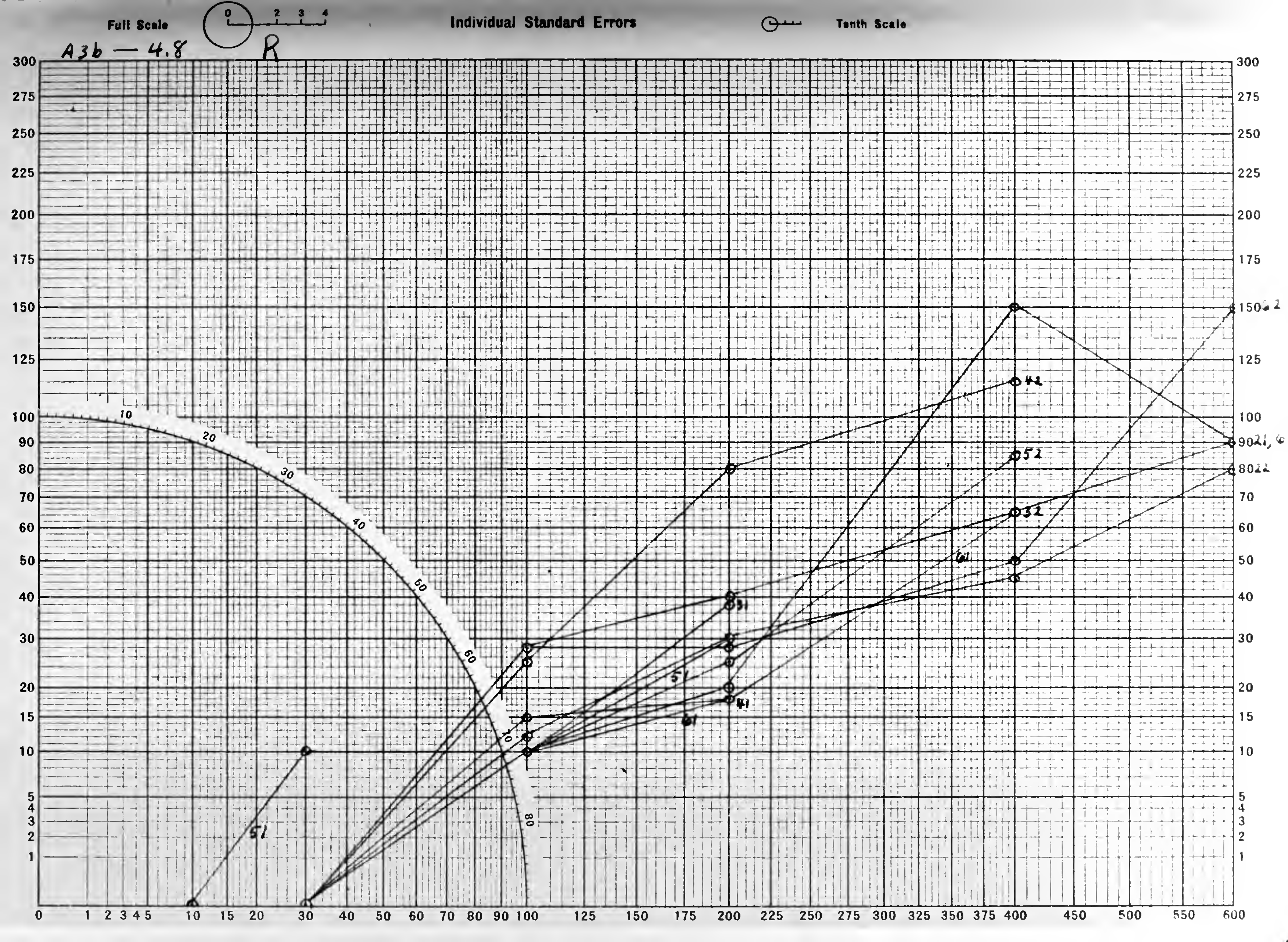

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2d — 5.8
R
351
231, 42
ALL OTHE

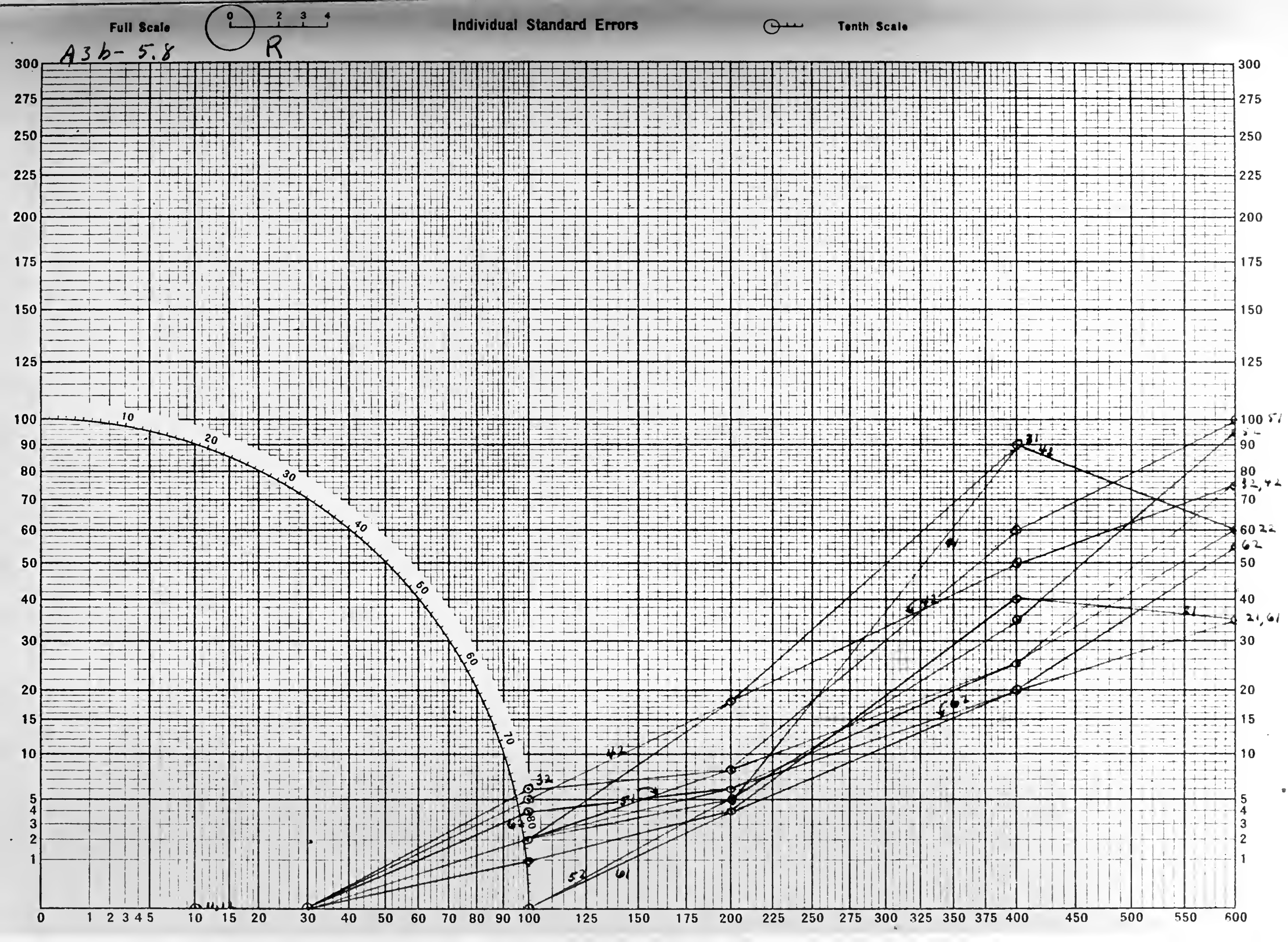

Full Scale
Tenth Scale
Individual Standard Errors
A 3a — 4.8 R
32
41
11,12
22
21
31
42
52
51

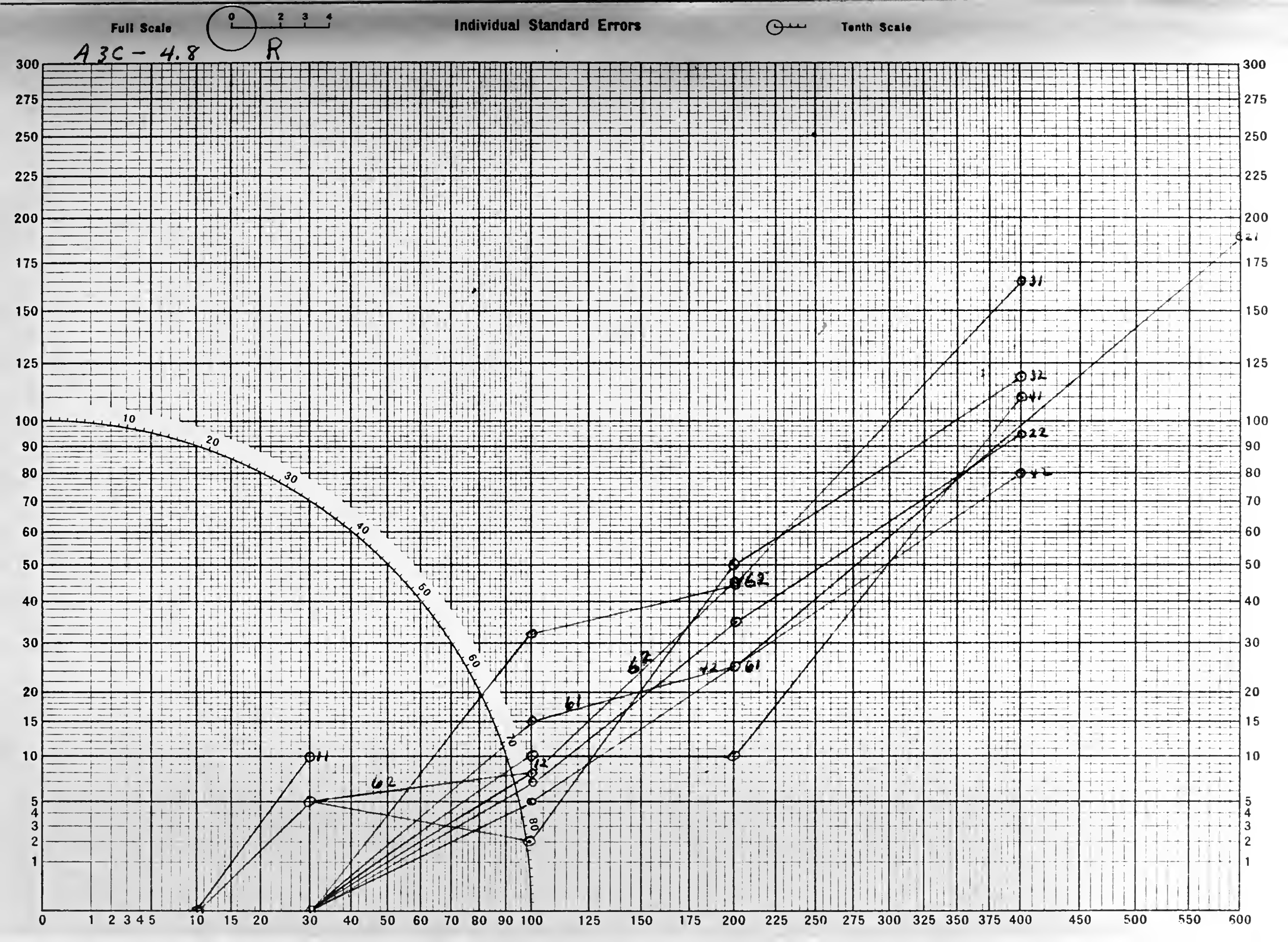
Full Scale Individual Standard Errors Tenth Scale

A 3a — 5.8 R




Full Scale
Individual Standard Errors
Tenth Scale
A3b — 4.8
R
51
41
61
52
32
42
62
21,6
22


Full Scale
Individual Standard Errors
Tenth Scale
A3b- 5.8
R



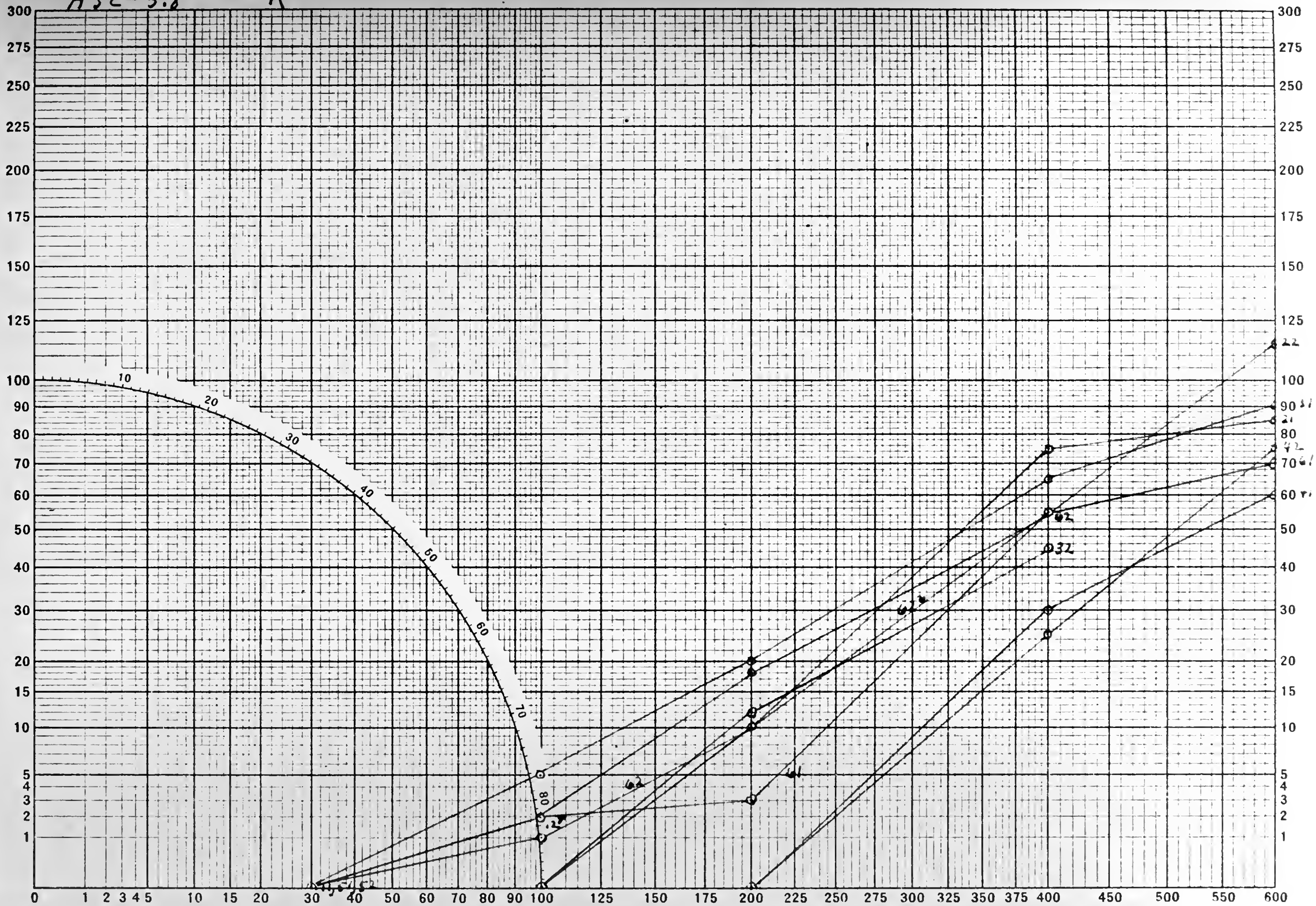
Full Scale
A3C - 4.8
R
Individual Standard Errors
Tenth Scale
11
12
22
31
32
41
42
61
62

Full Scale

Individual Standard Errors

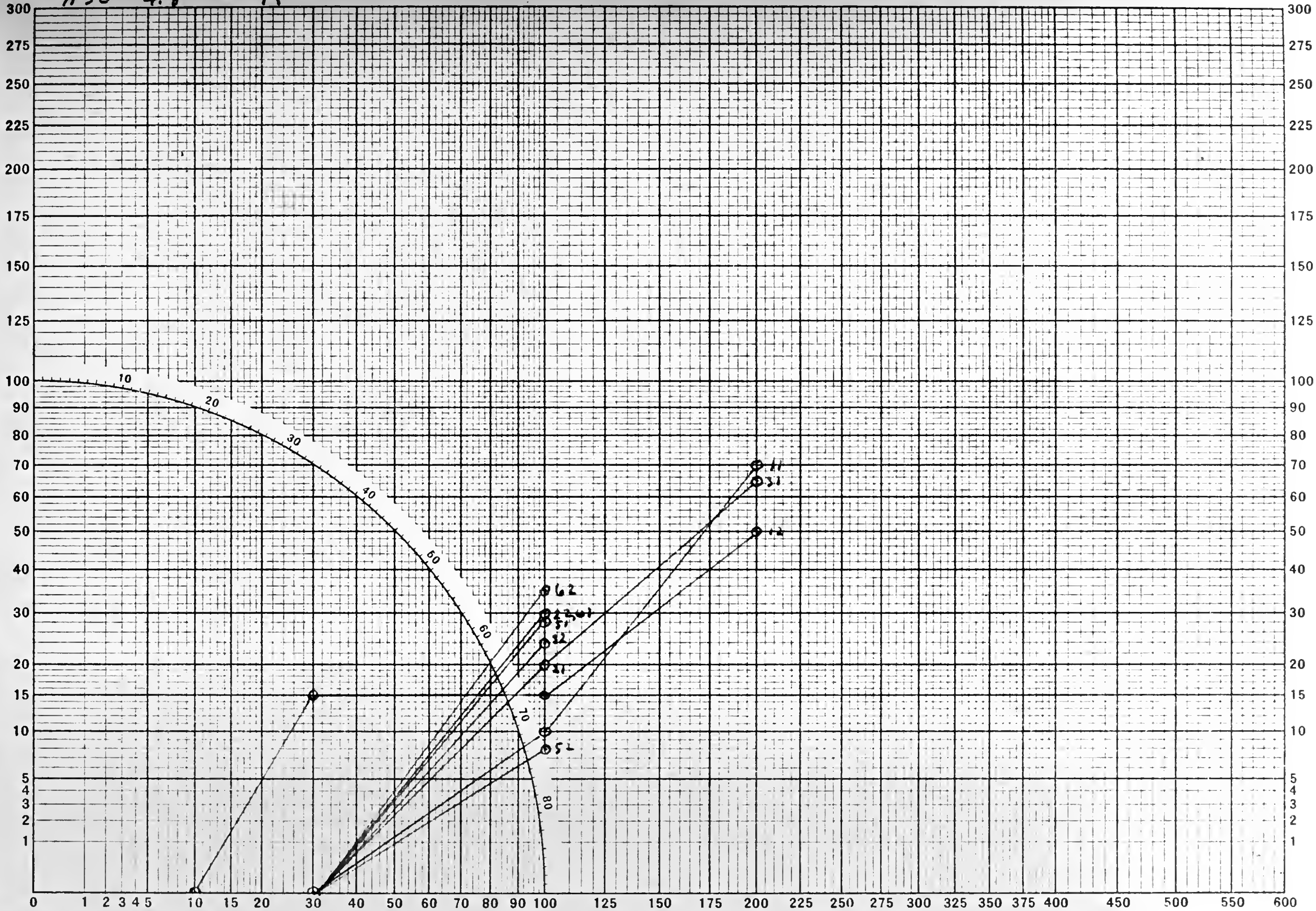
Tenth Scale

A3C-5.8 R



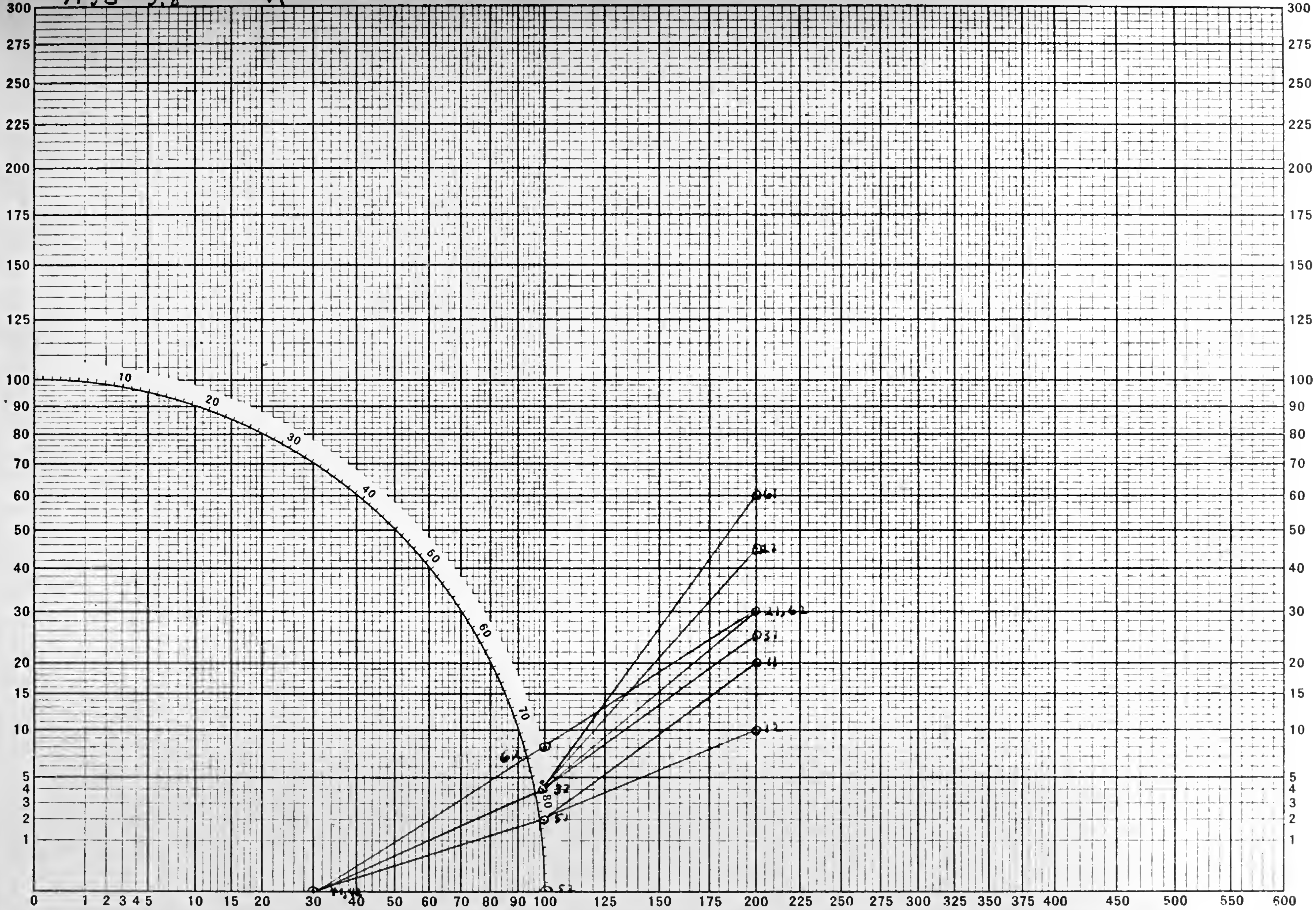
Full Scale Individual Standard Errors Tenth Scale

A'3d - 4.8 R



Full Scale   Individual Standard Errors   Tenth Scale

A3d-5.8   R



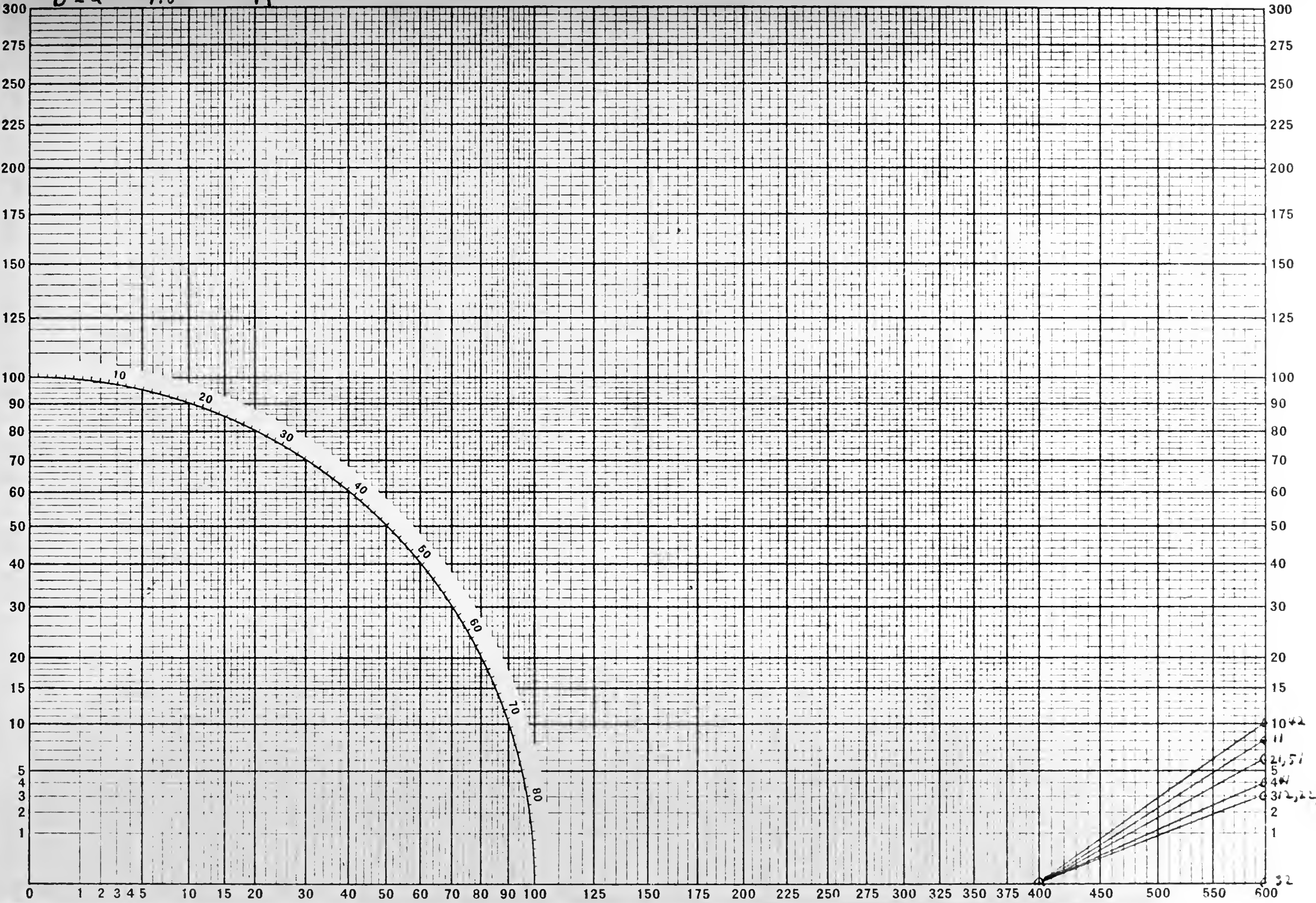
Full Scale

Individual Standard Errors

Tenth Scale

B 2a — 4.8

R

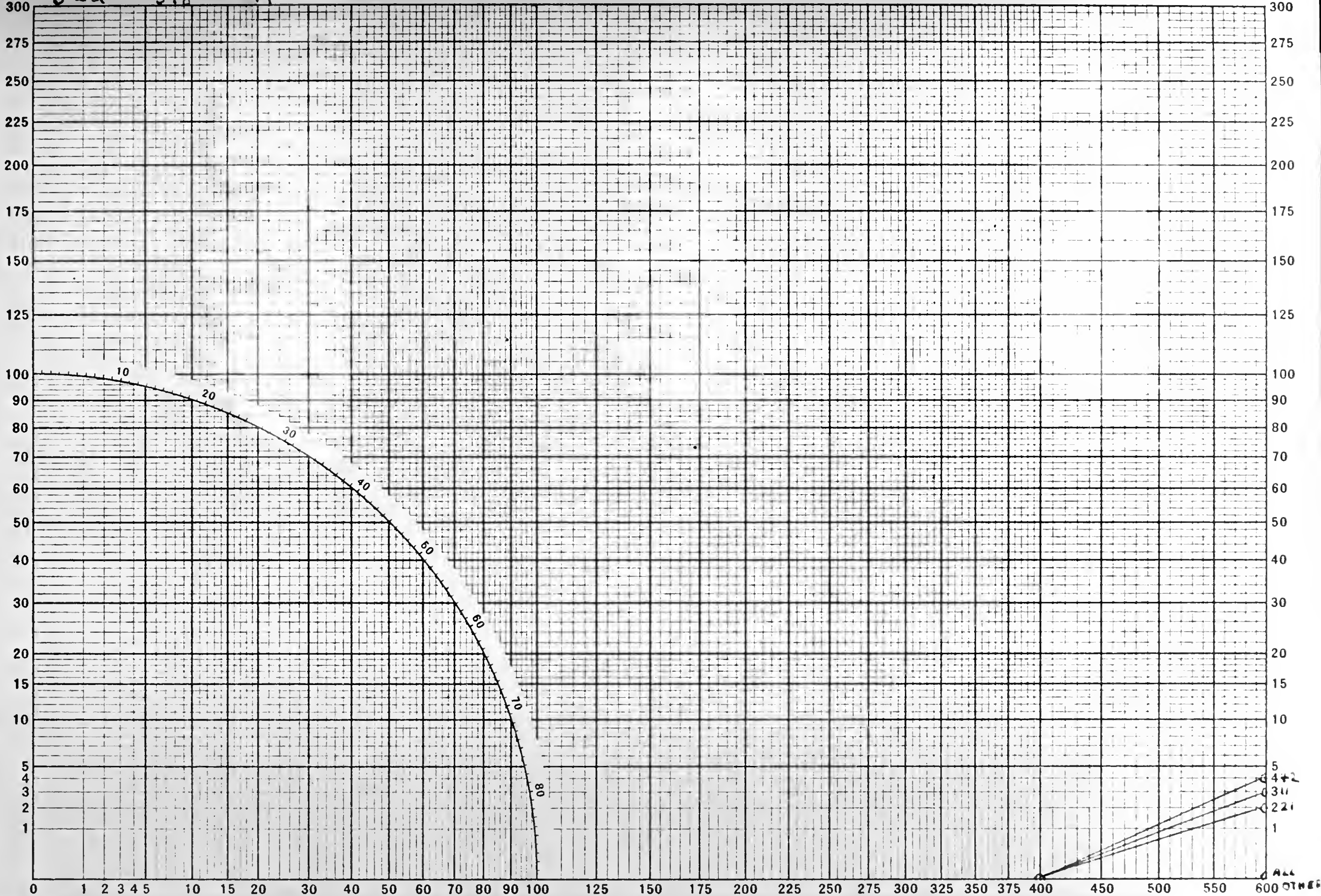


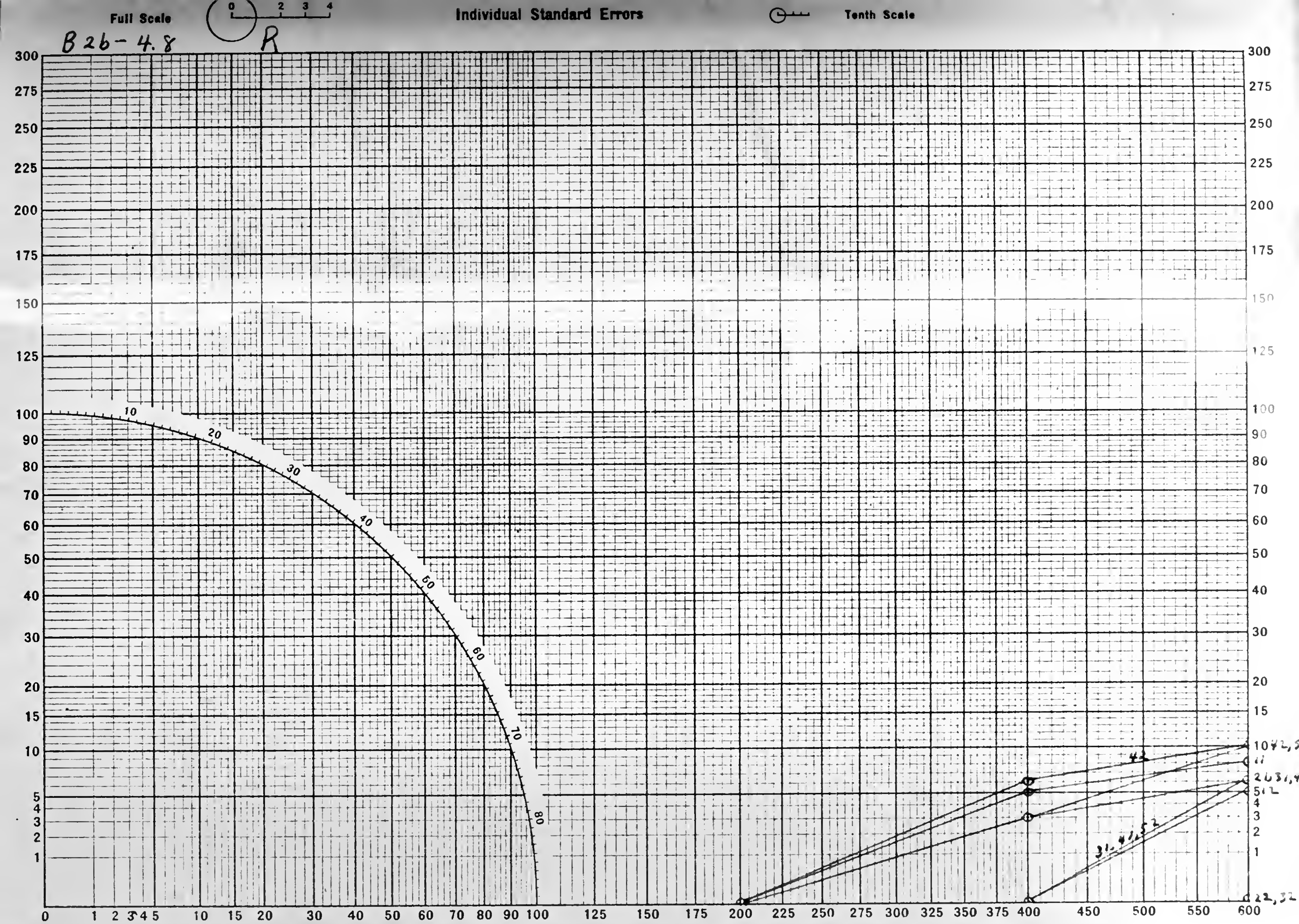
Full Scale

Individual Standard Errors

Tenth Scale

B 2a — 5.8 R





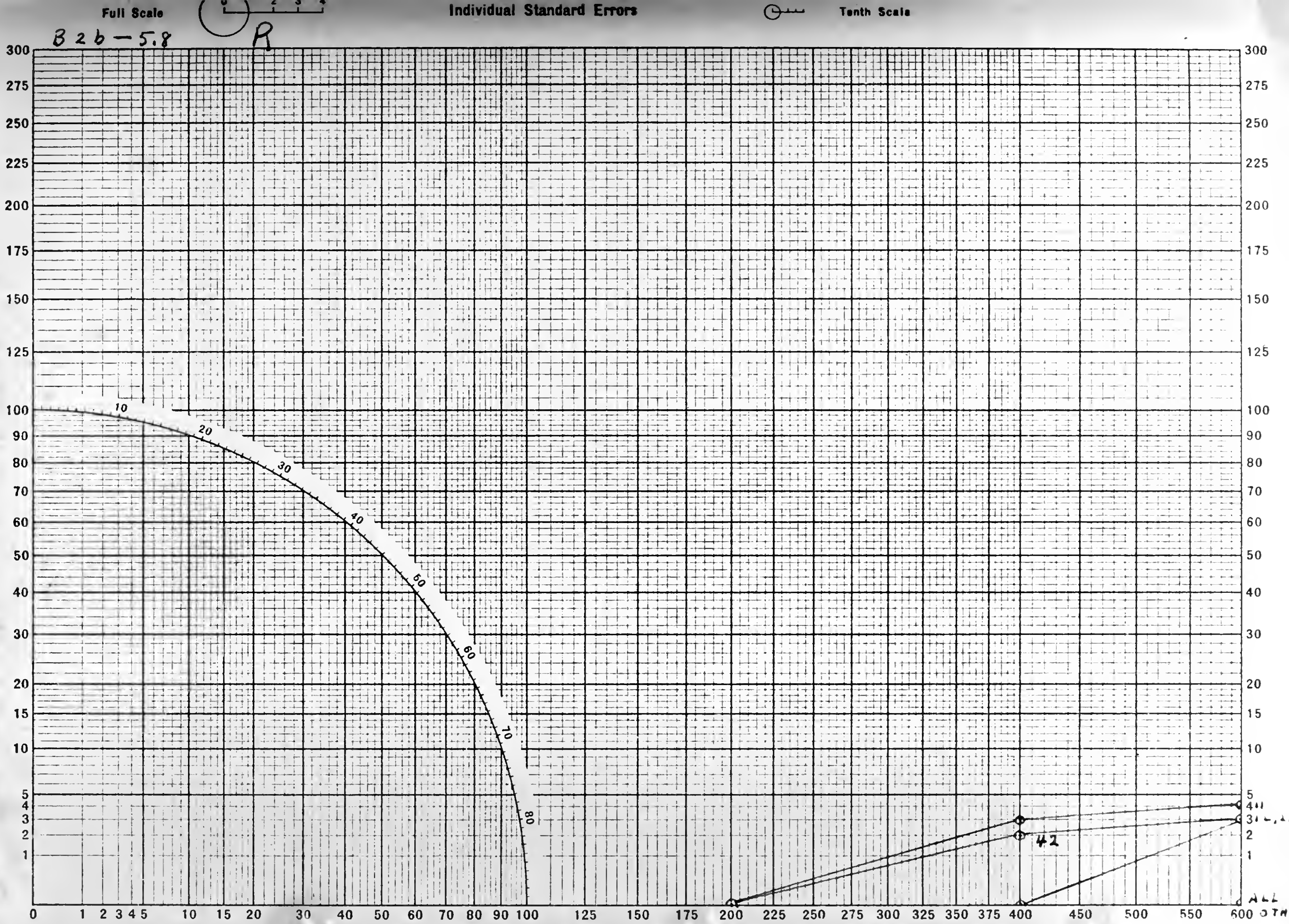
Full Scale
Individual Standard Errors
Tenth Scale
B 2b-4.8
R

Full Scale

Individual Standard Errors

Tenth Scale

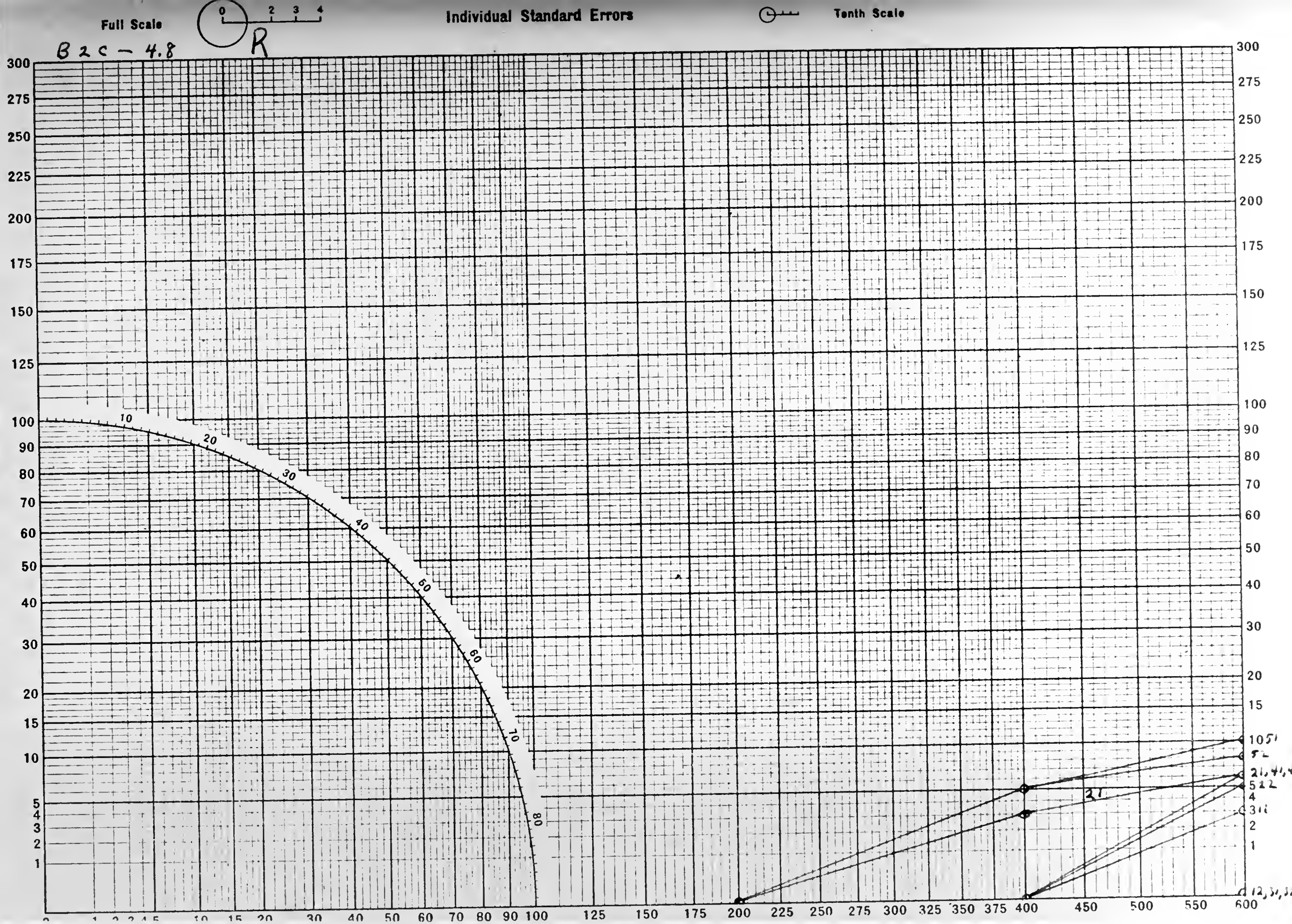
B 2 b — 5.8



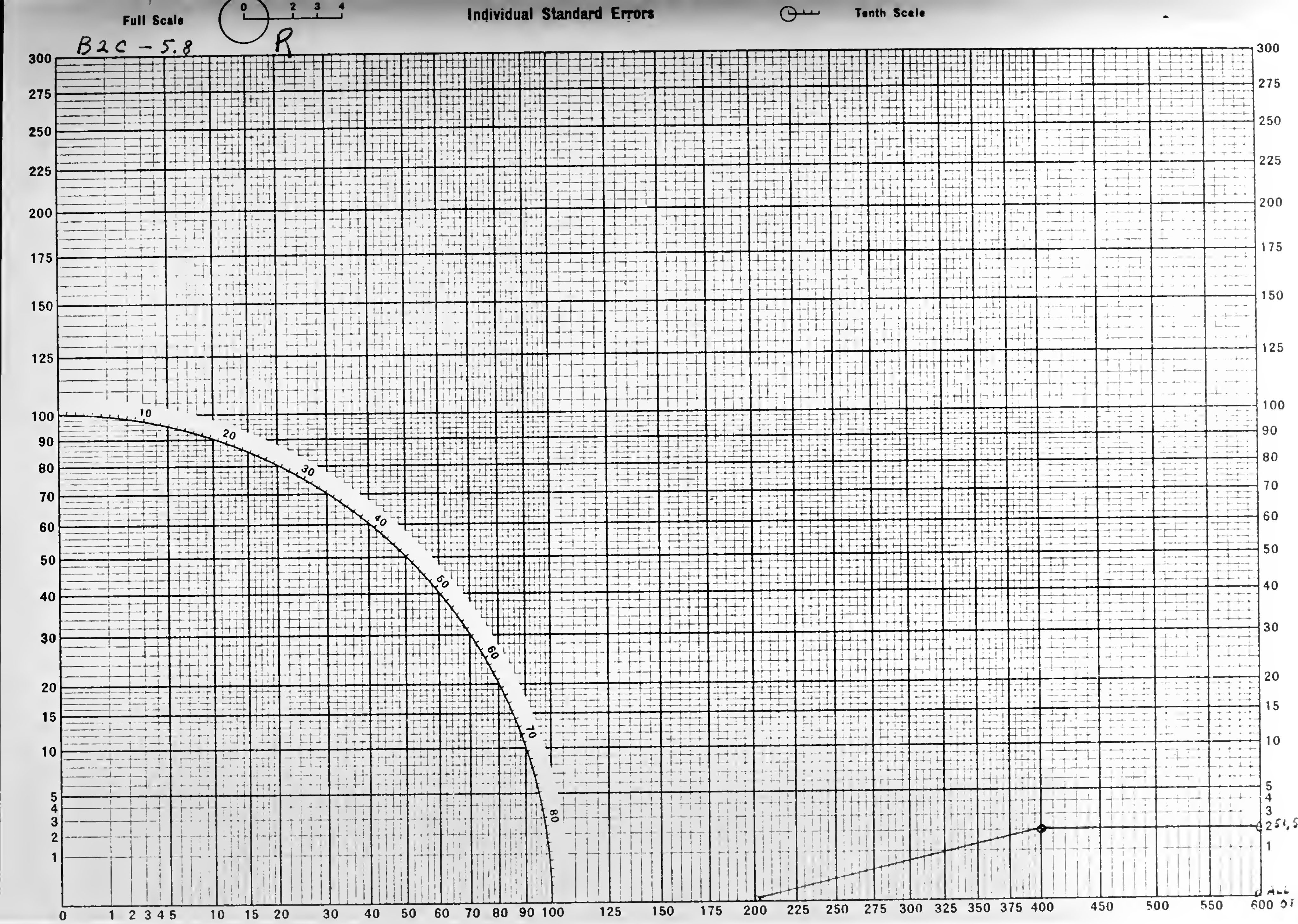
Full Scale

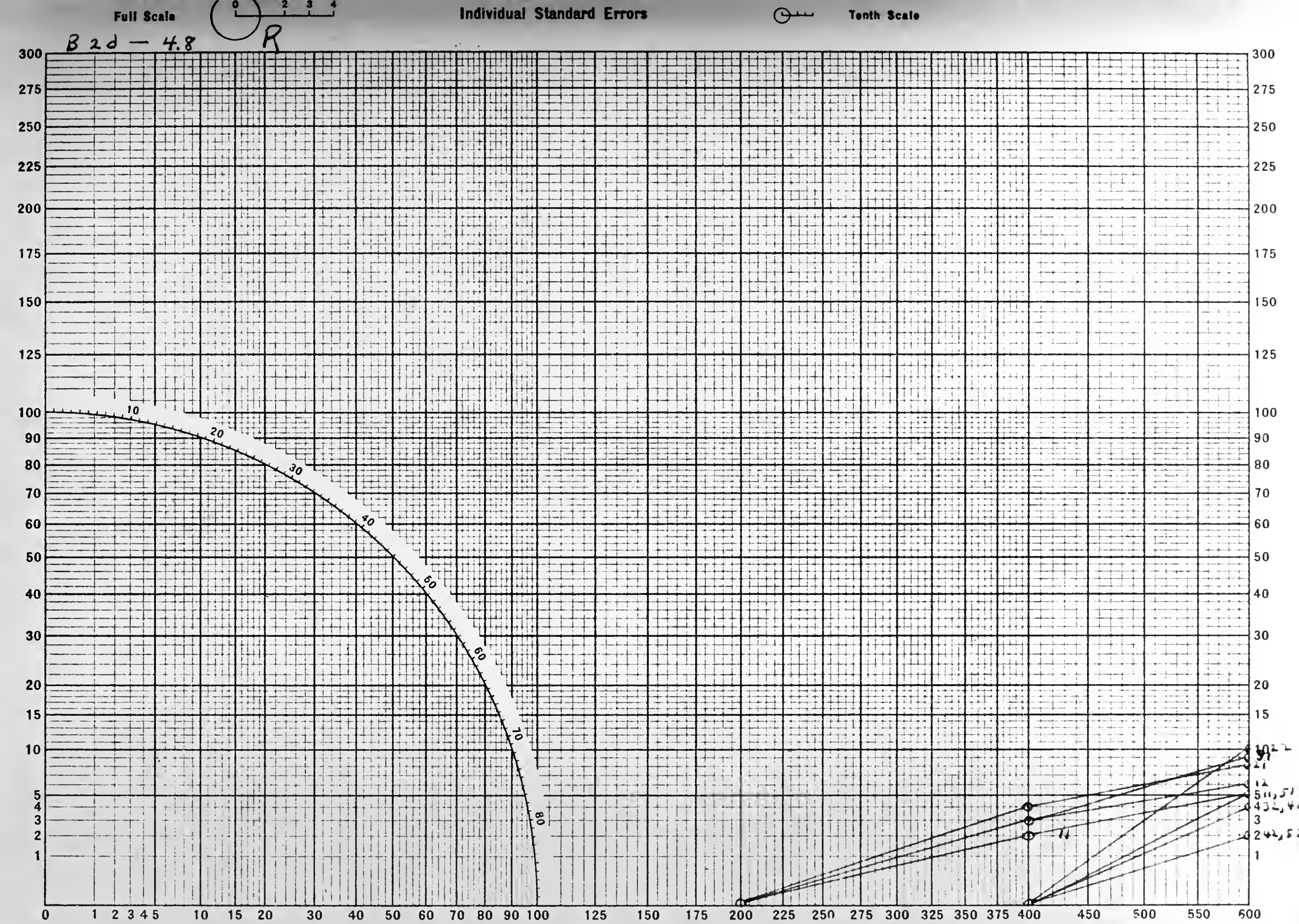
Individual Standard Errors

Tenth Scale



B2C - 5.8





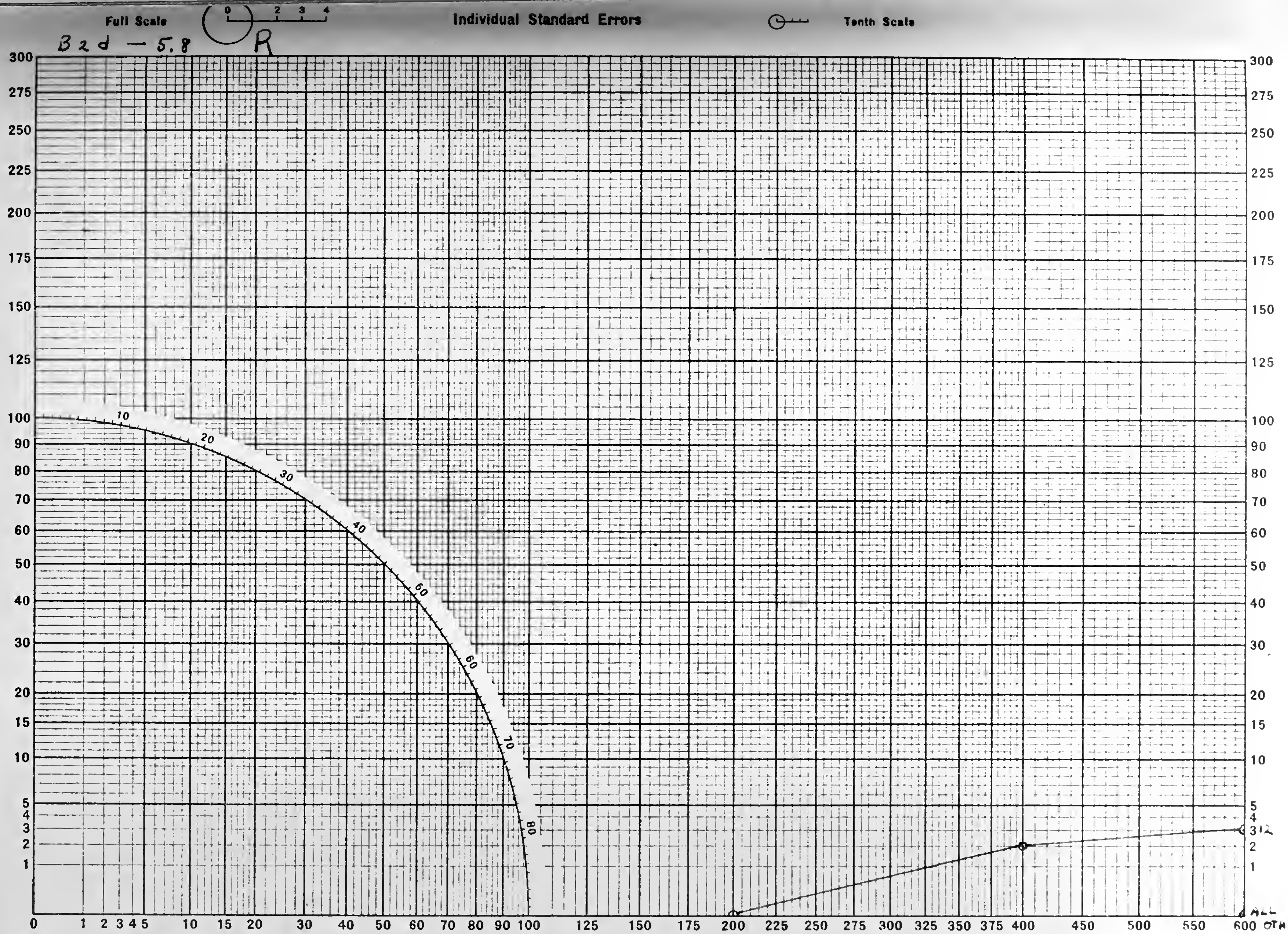
Full Scale
Individual Standard Errors
Tenth Scale
B 2d — 4.8
R

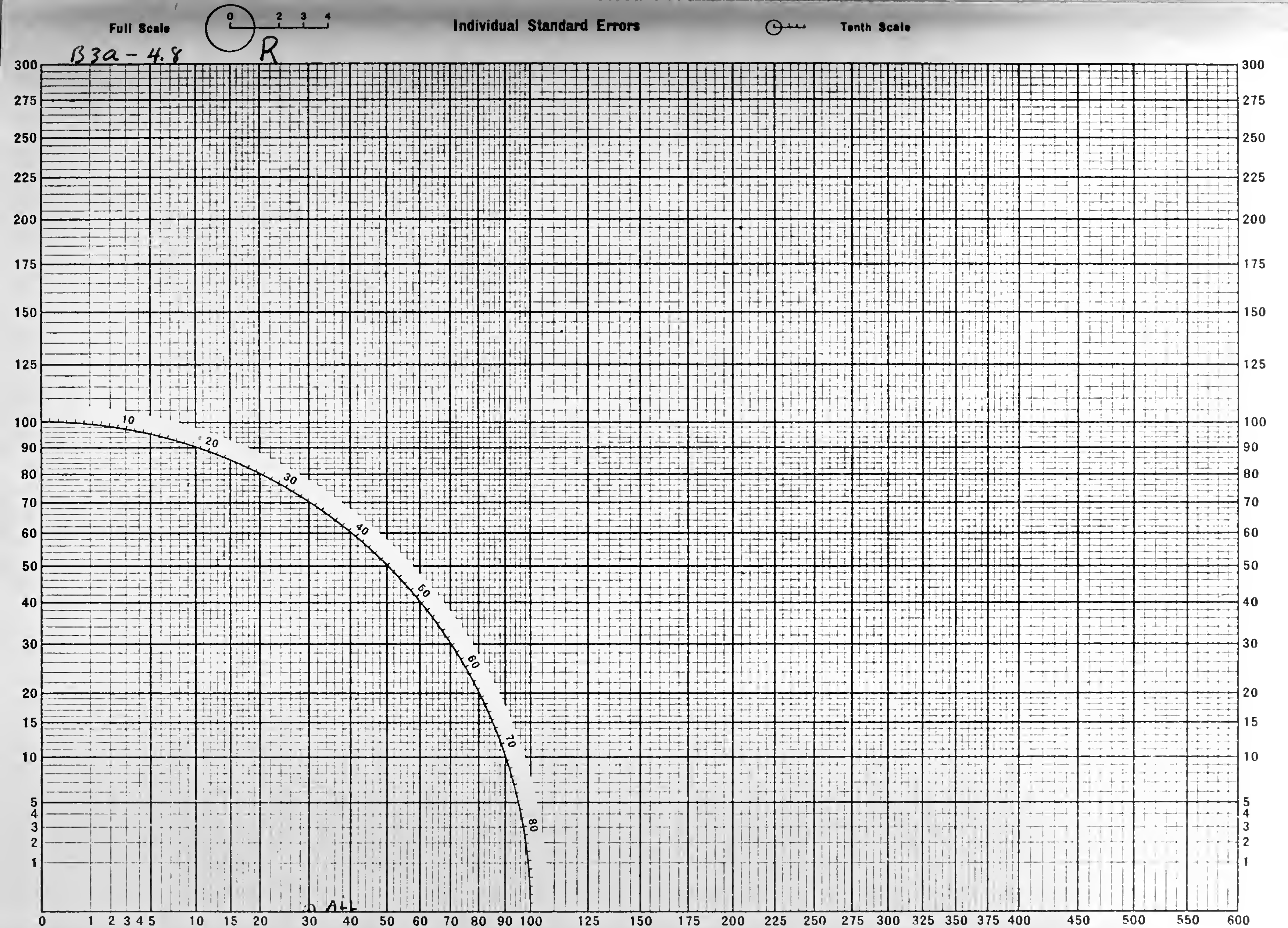

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B2d — 5.8
R
ALL OTHE
312

Full Scale

Individual Standard Errors

Tenth Scale




Full Scale
Individual Standard Errors
Tenth Scale
B3a - 4.8
R

Full Scale

B3a - 5.8

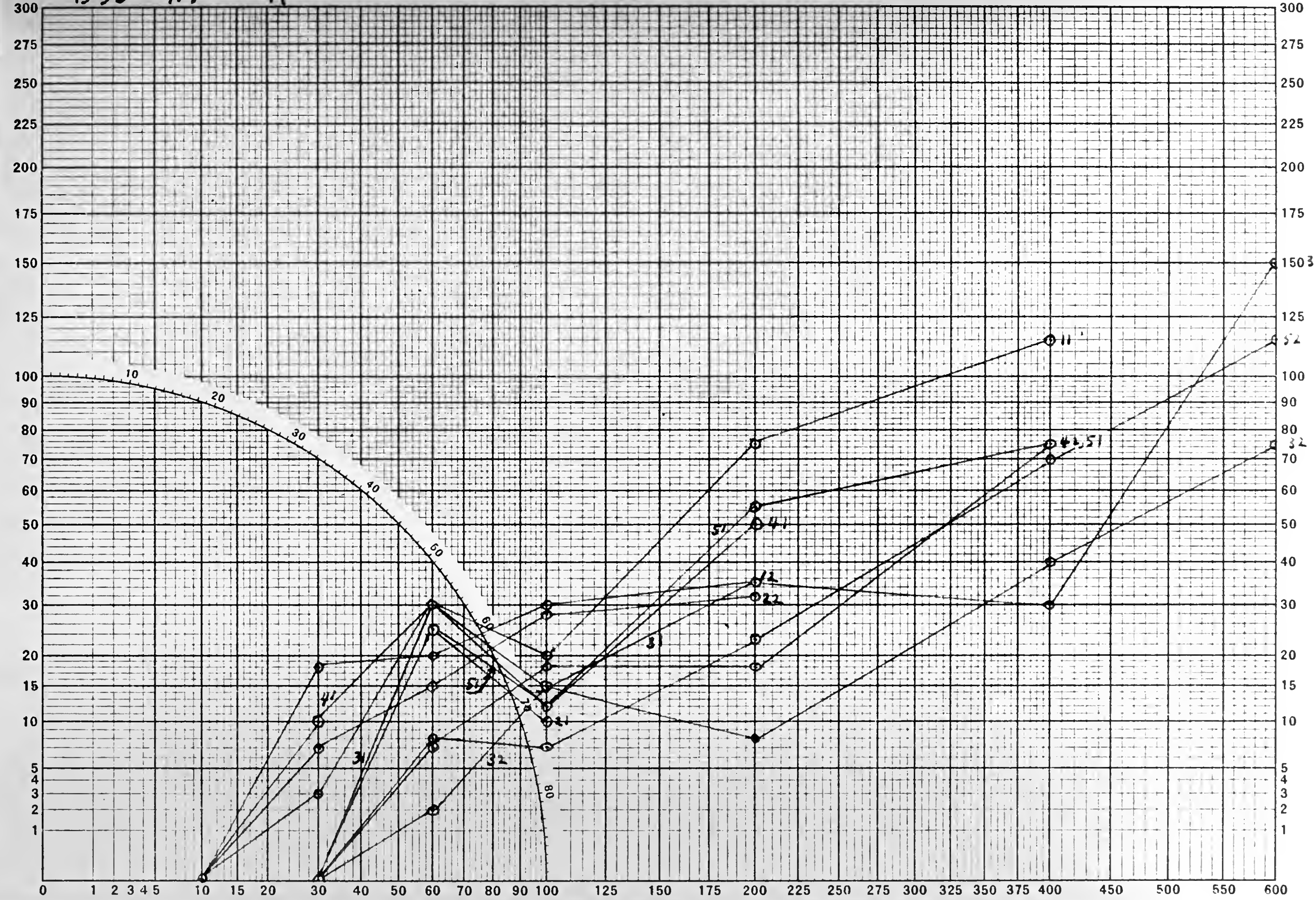
R

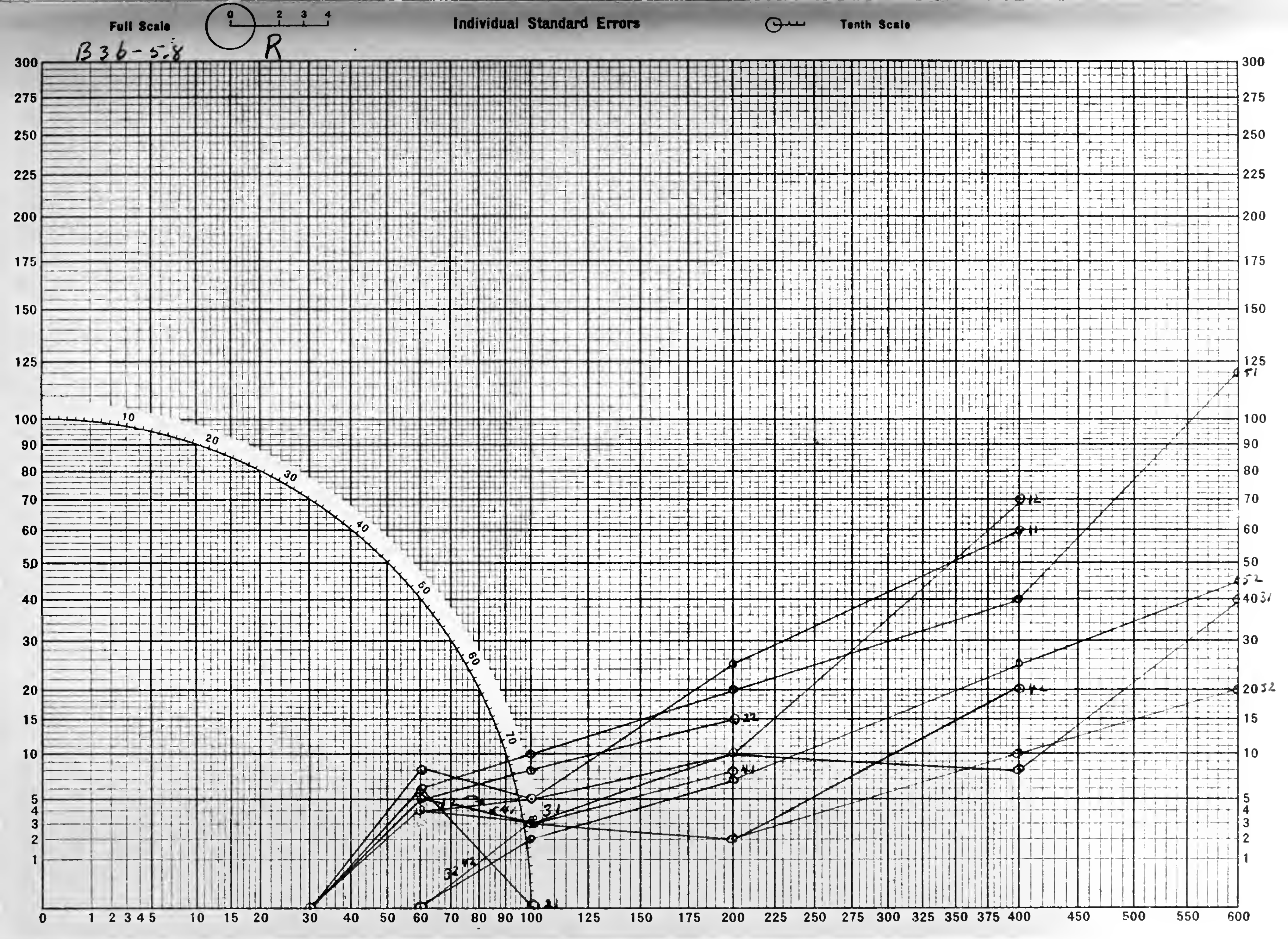
Individual Standard Errors

Tenth Scale

Full Scale · 0 2 3 4 **Individual Standard Errors** Tenth Scale

B3b – 4.8 R





Full Scale
B36-5.8
R
Individual Standard Errors
Tenth Scale

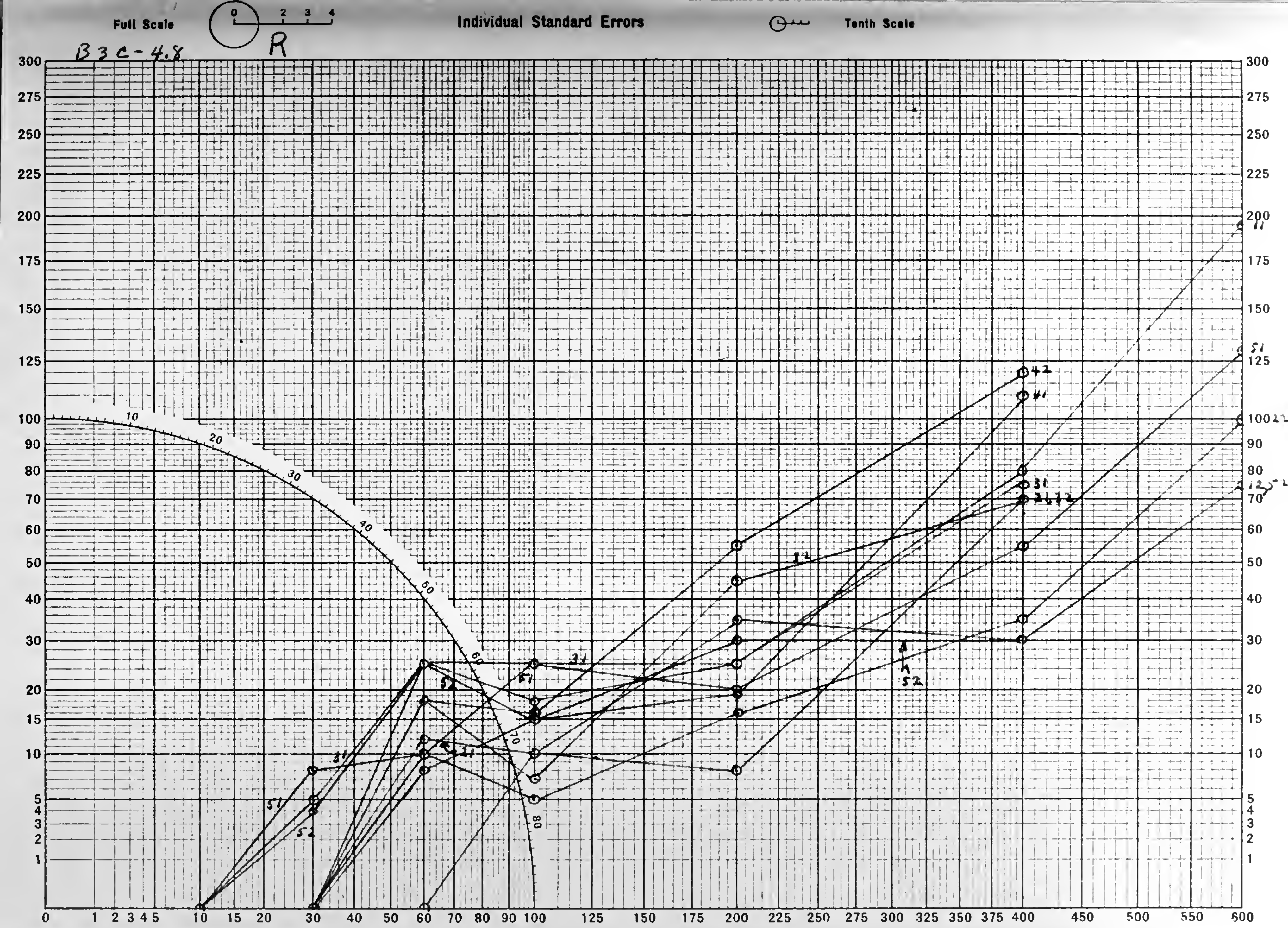
Full Scale

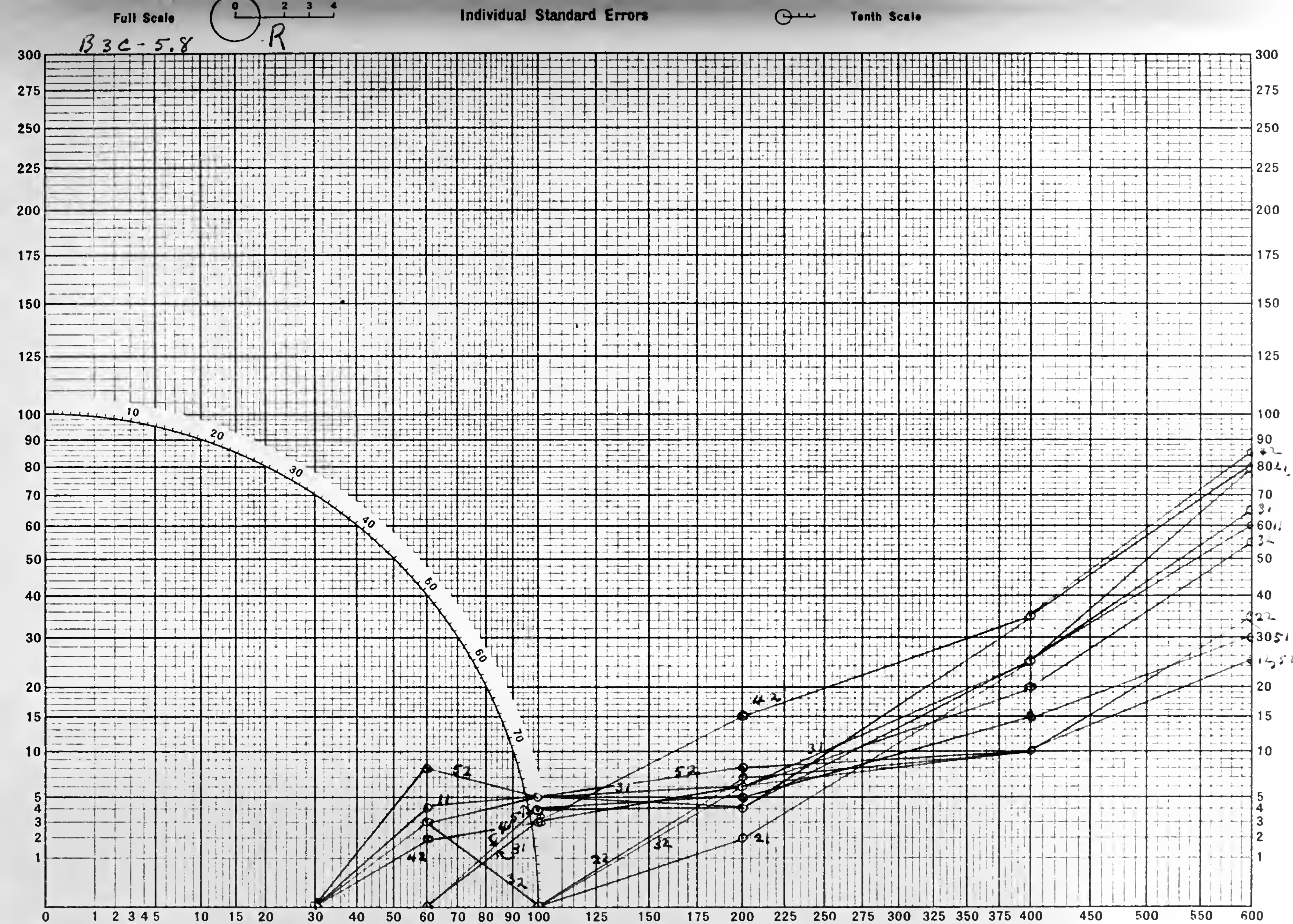
Individual Standard Errors

Tenth Scale

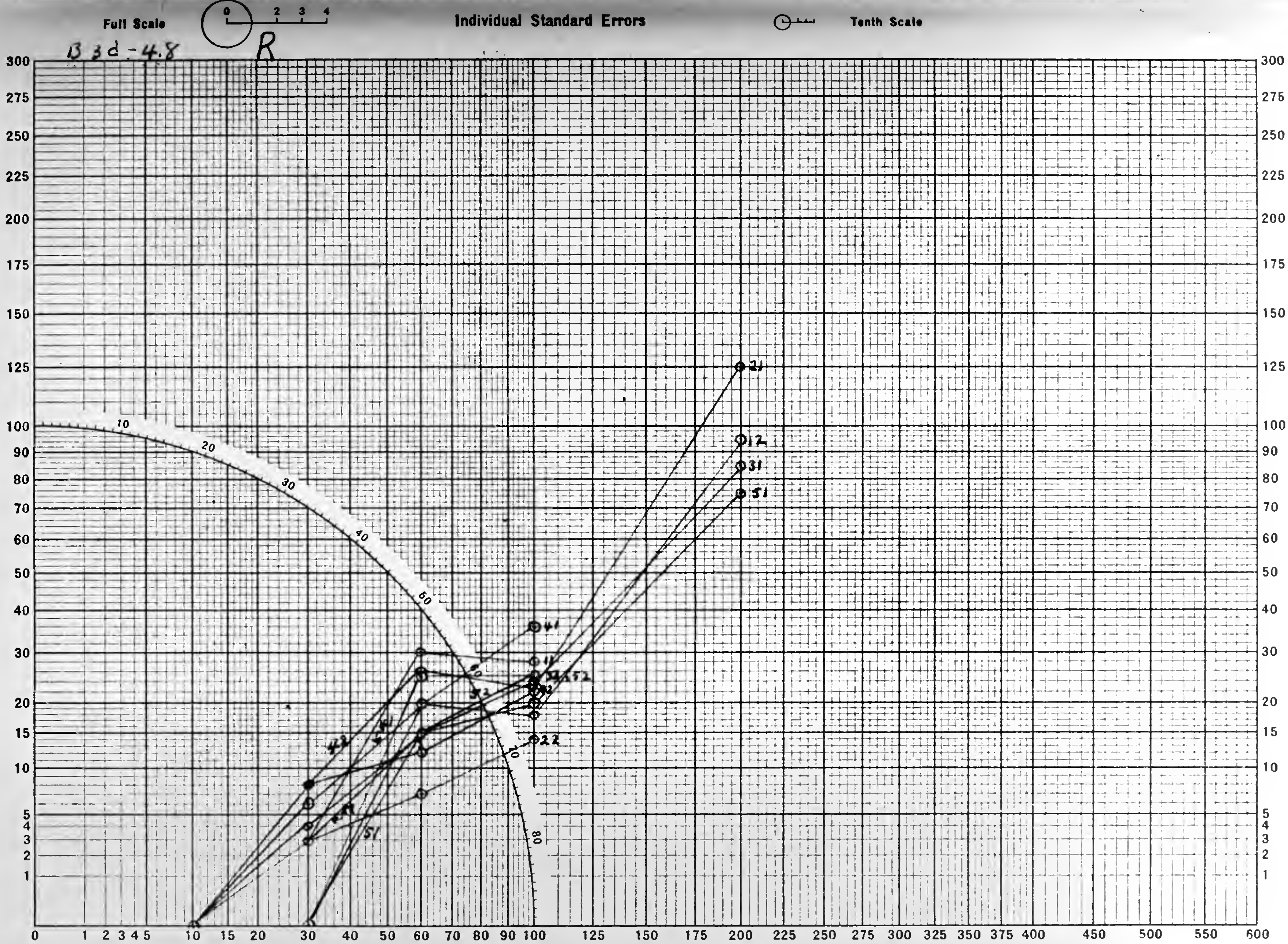
B3C-4.8

R





Full Scale
0 2 3 4
R
B3C-5.8
Individual Standard Errors
Tenth Scale
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70
52
11
42
31
32
22
21

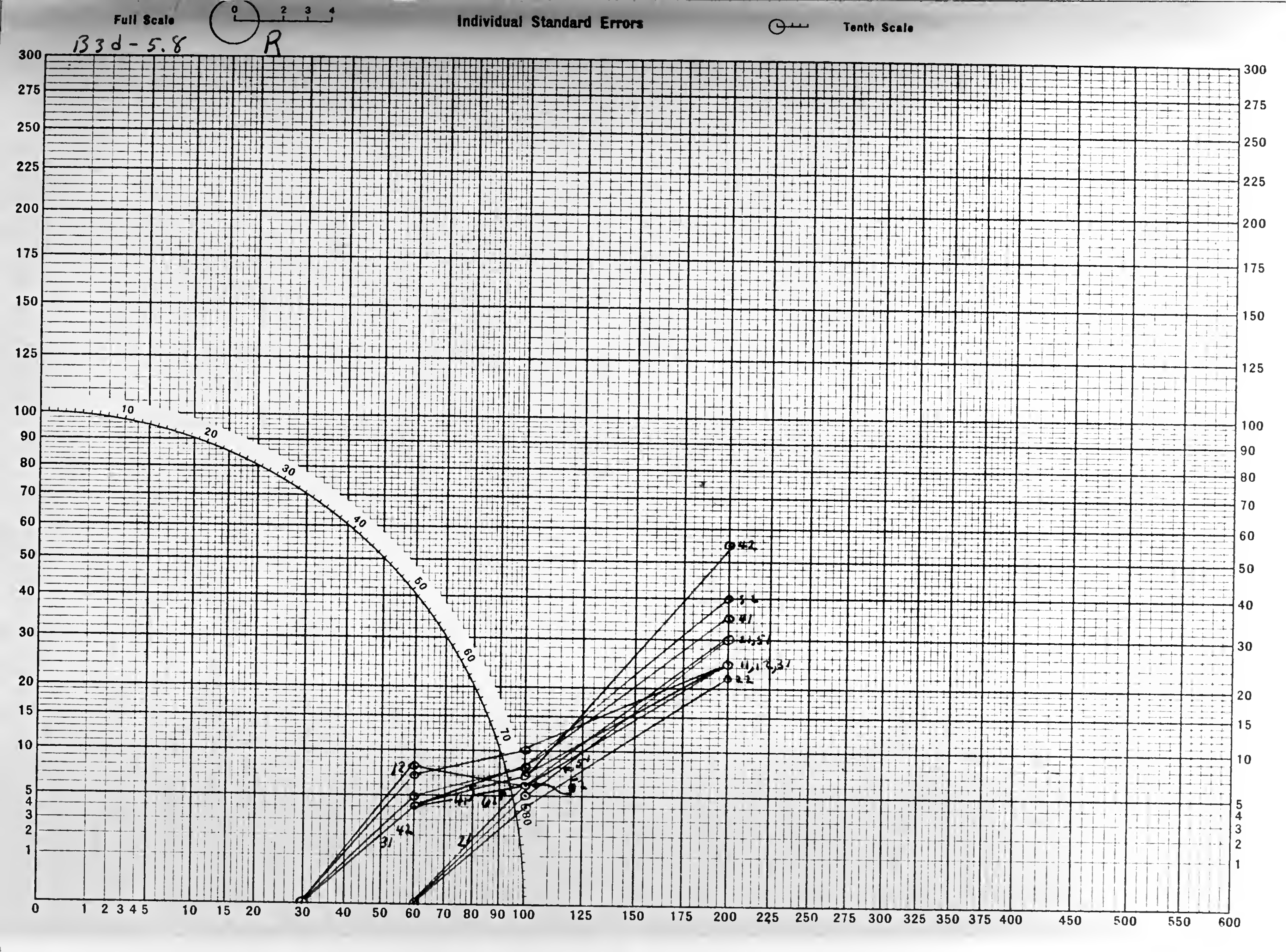


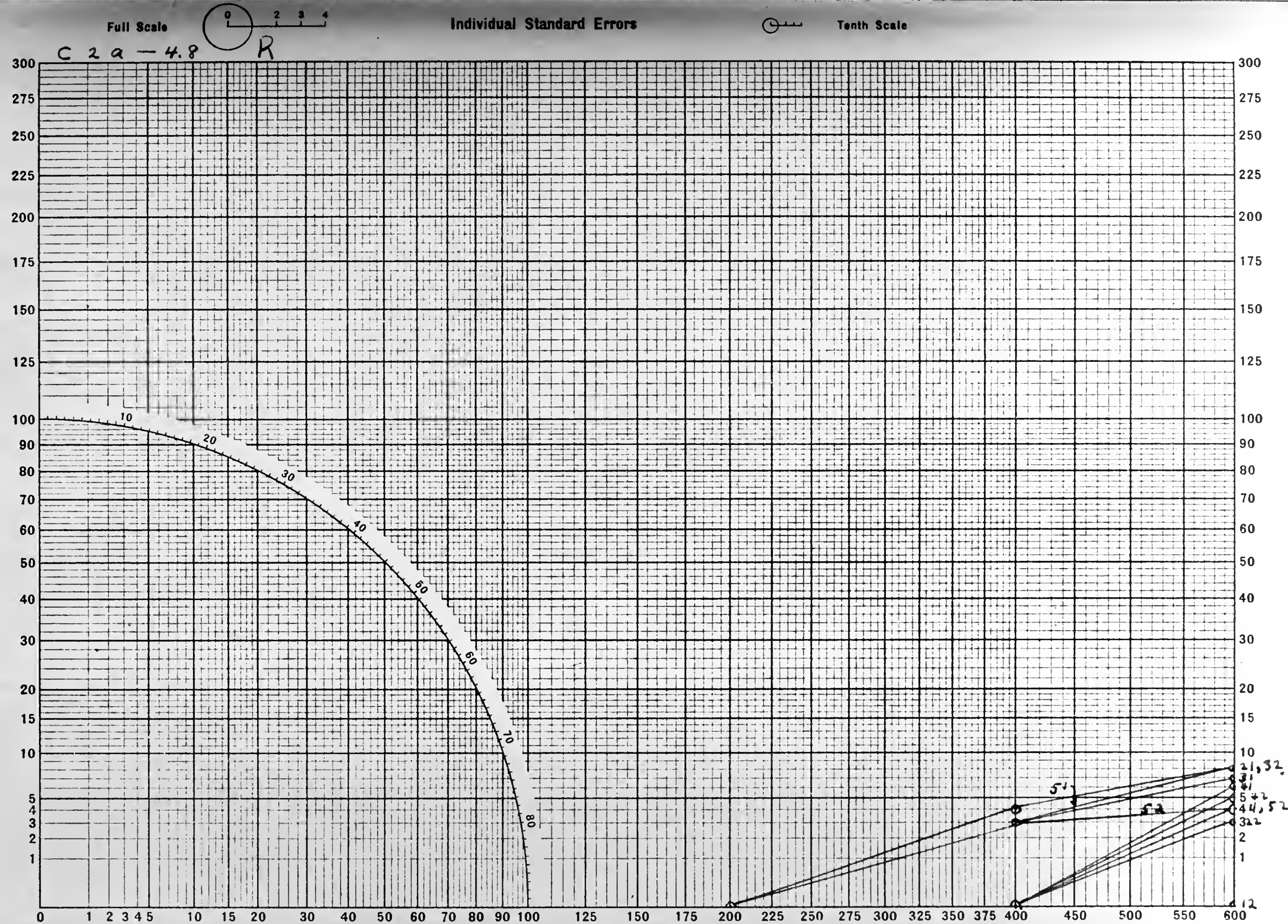
Full Scale
Individual Standard Errors
Tenth Scale
B 3d - 4.8
R
21
12
31
51
41
11
22
42

Full Scale

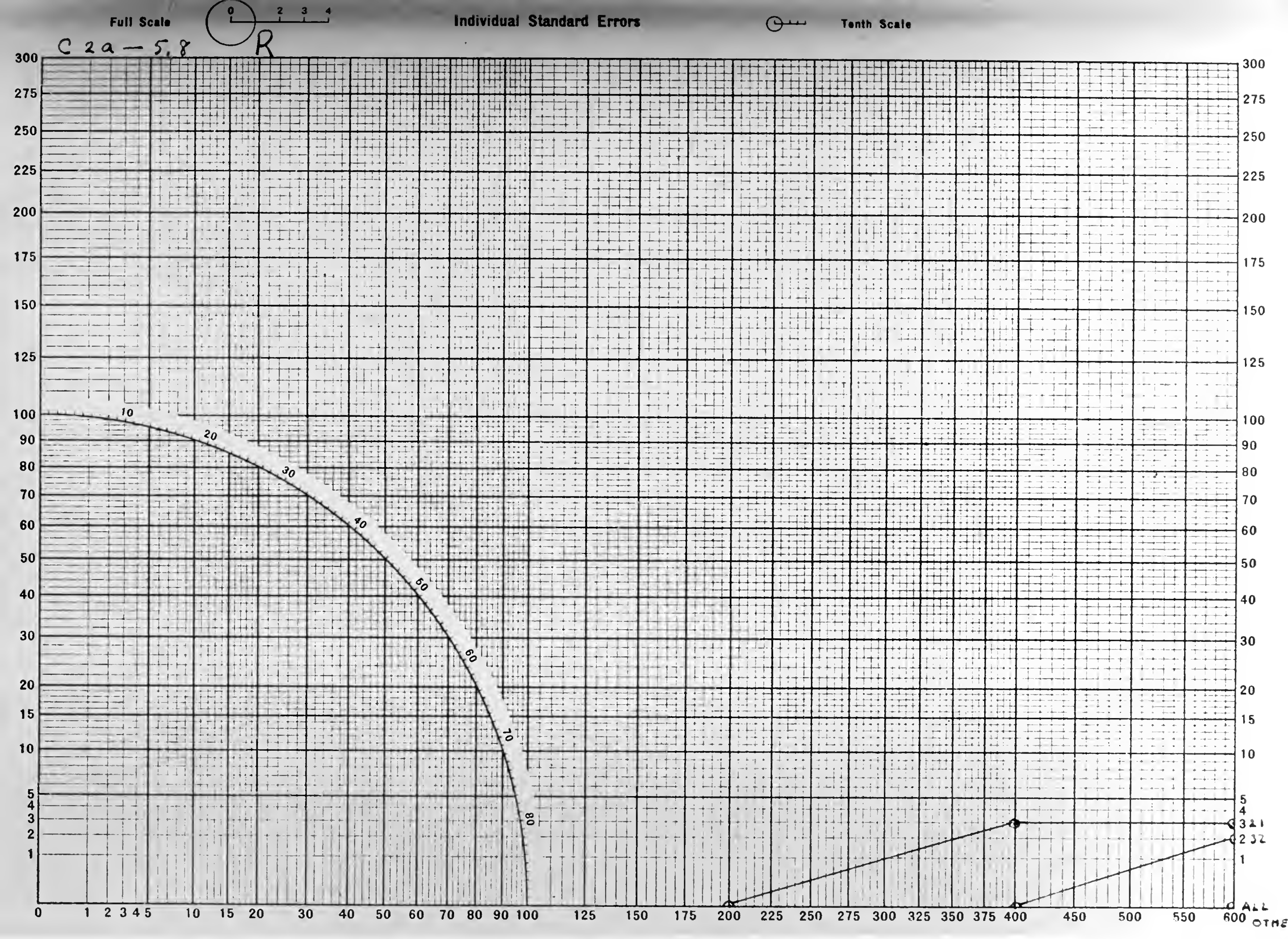
Individual Standard Errors

Tenth Scale



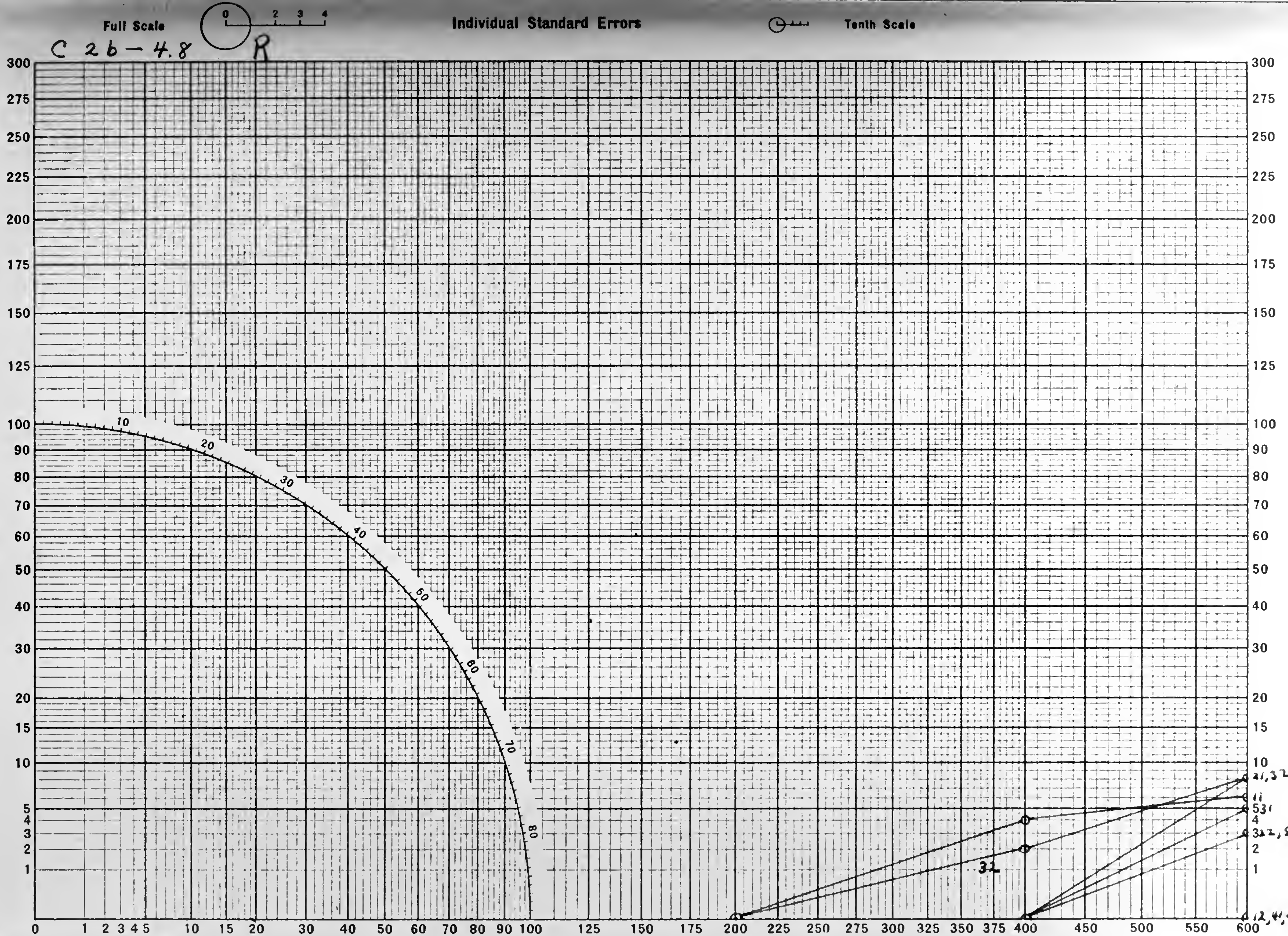


Full Scale
Individual Standard Errors
Tenth Scale
C 2 a — 4.8
R
21, 32,
31
41
5 42
44, 52
322
12
51
52



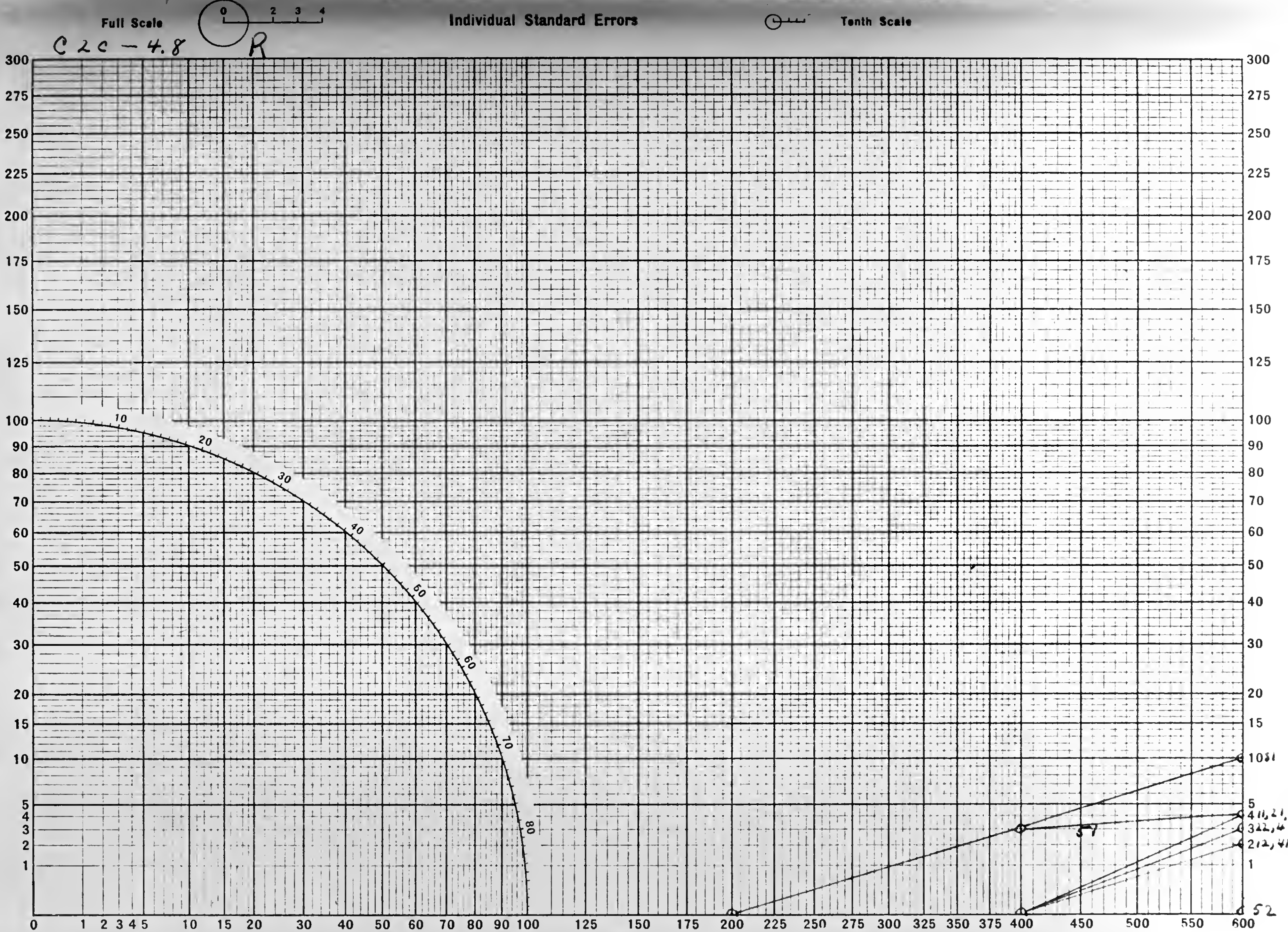
Full Scale
Individual Standard Errors
Tenth Scale
C 2a — 5.8
R

C 2b — 4.8

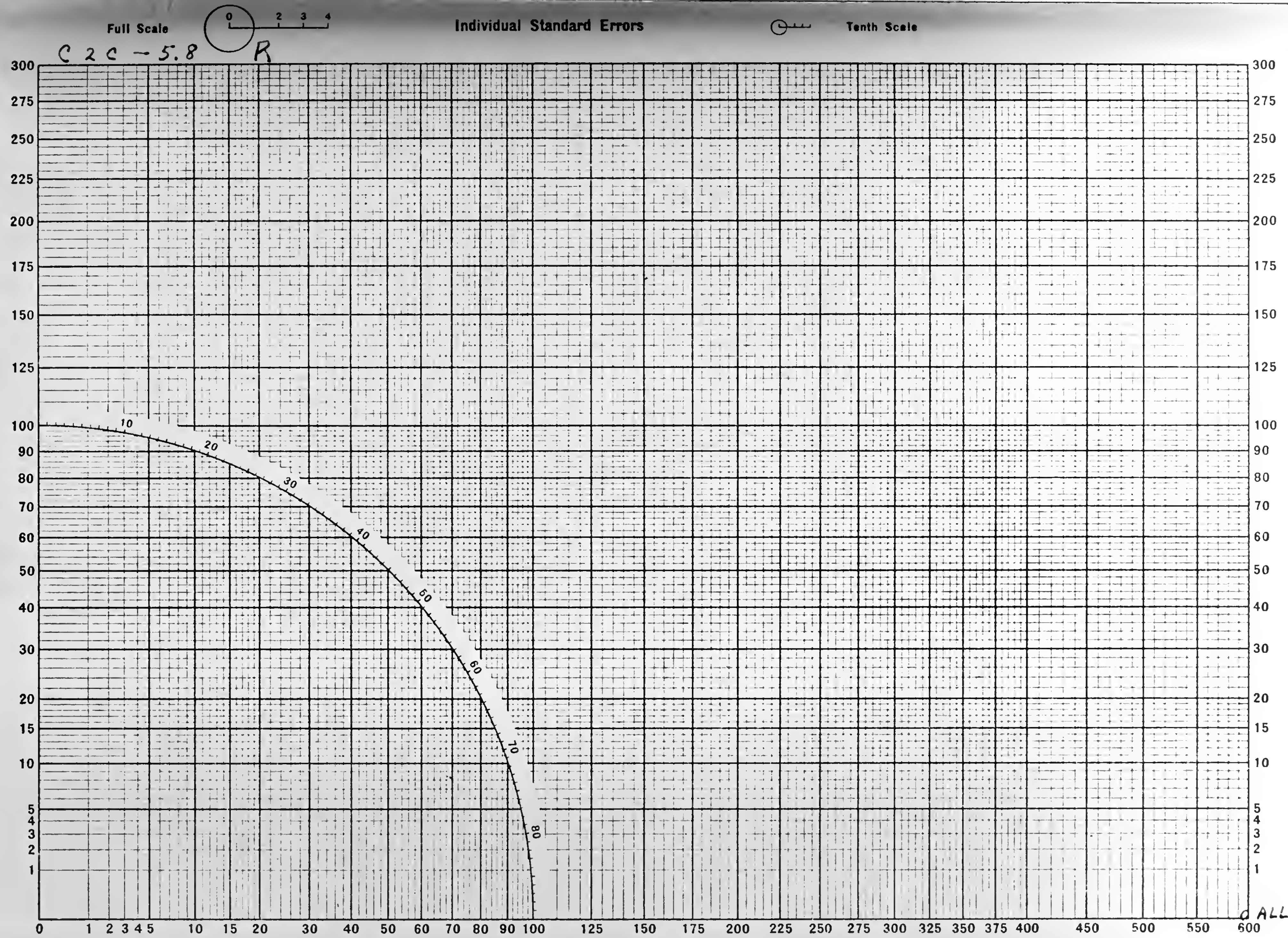


Full Scale
0
2
3
4
R
Individual Standard Errors
Tenth Scale
21,32
11
531
32

Full Scale
C 26 - 5.8
R
Individual Standard Errors
Tenth Scale
311
232
ALL OTHE



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2 C − 4.8
R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10 15 20 30 40 50 60 70 80 90 100
125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80
1031
411,21,3
312,42
212,41
52
57

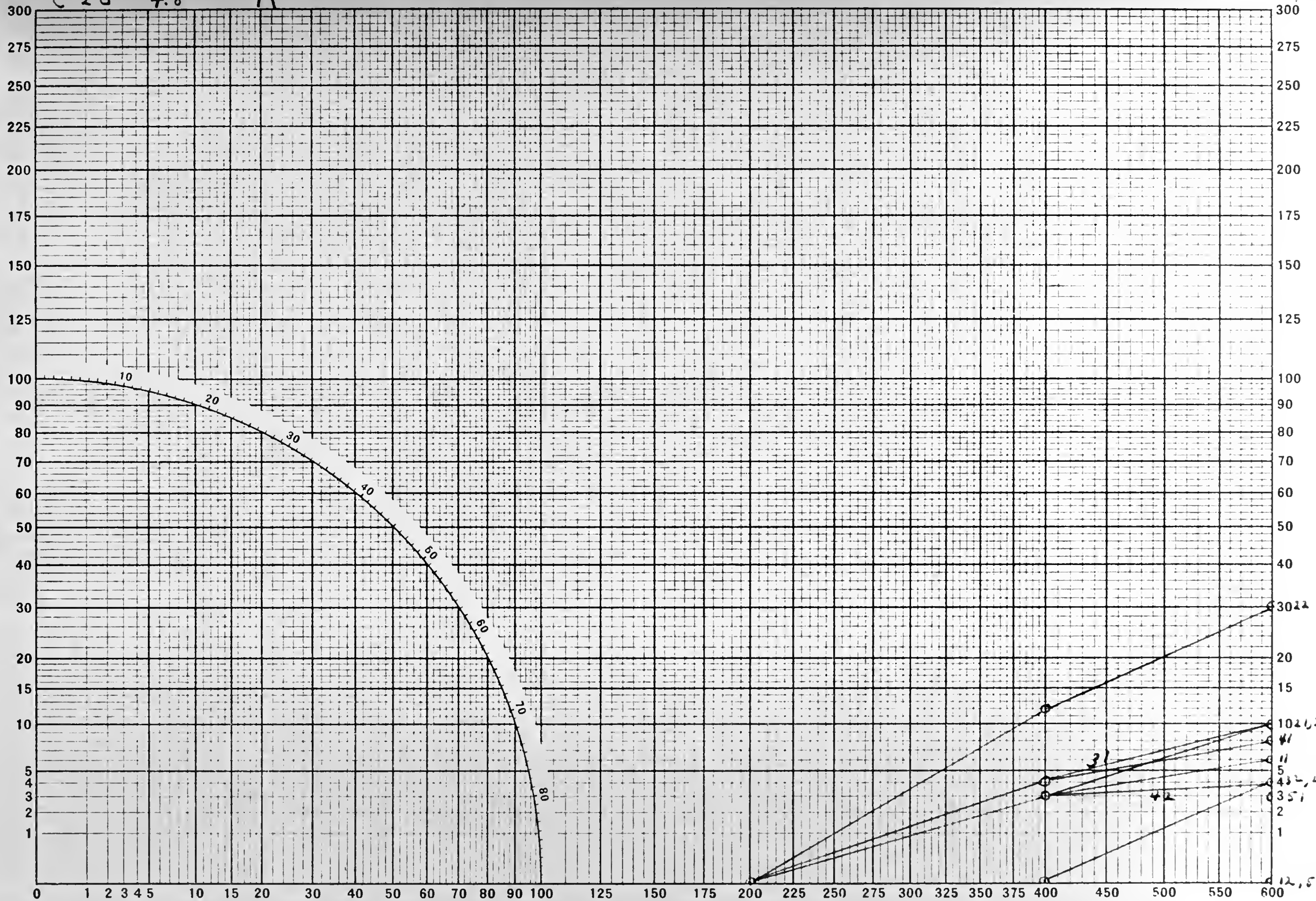

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2 C - 5.8
R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10
15
20
30
40
50
60
70
80
90
100
125
150
175
200
225
250
275
300
325
350
375
400
450
500
550
600
ALL

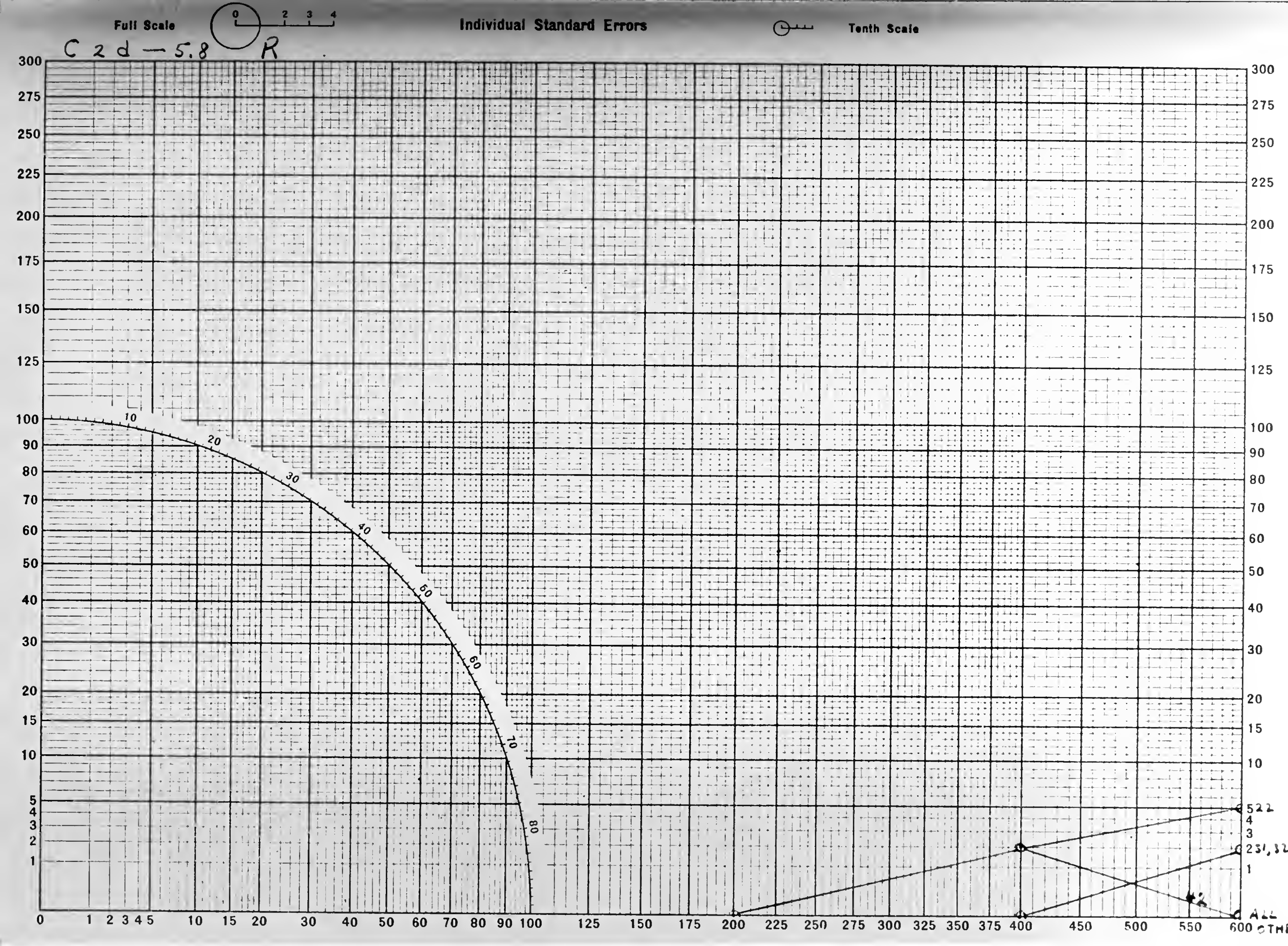
Full Scale

Individual Standard Errors

Tenth Scale

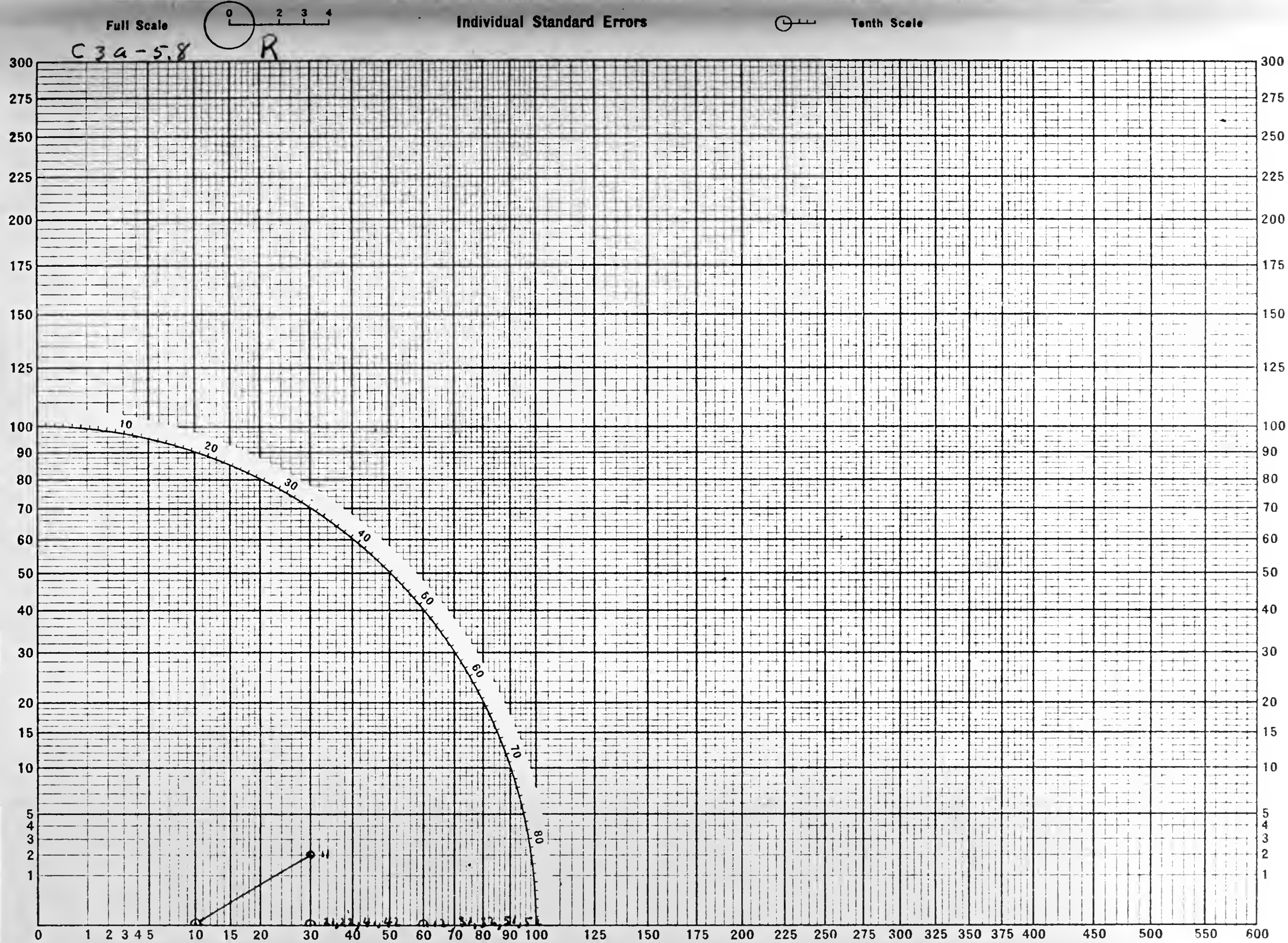
C 2d - 4.8 R





Full Scale
Individual Standard Errors
Tenth Scale
C 2 d — 5.8
R
522
231, 32
ALL OTHE

Full Scale
0 2 3 4
C3a-4.8
R
Individual Standard Errors
Tenth Scale
10 20 30 40 50 60 70 80
II
ALL OTHERS


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 3a-5.8
R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10
15
20
30
40
50
60
70
80
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100
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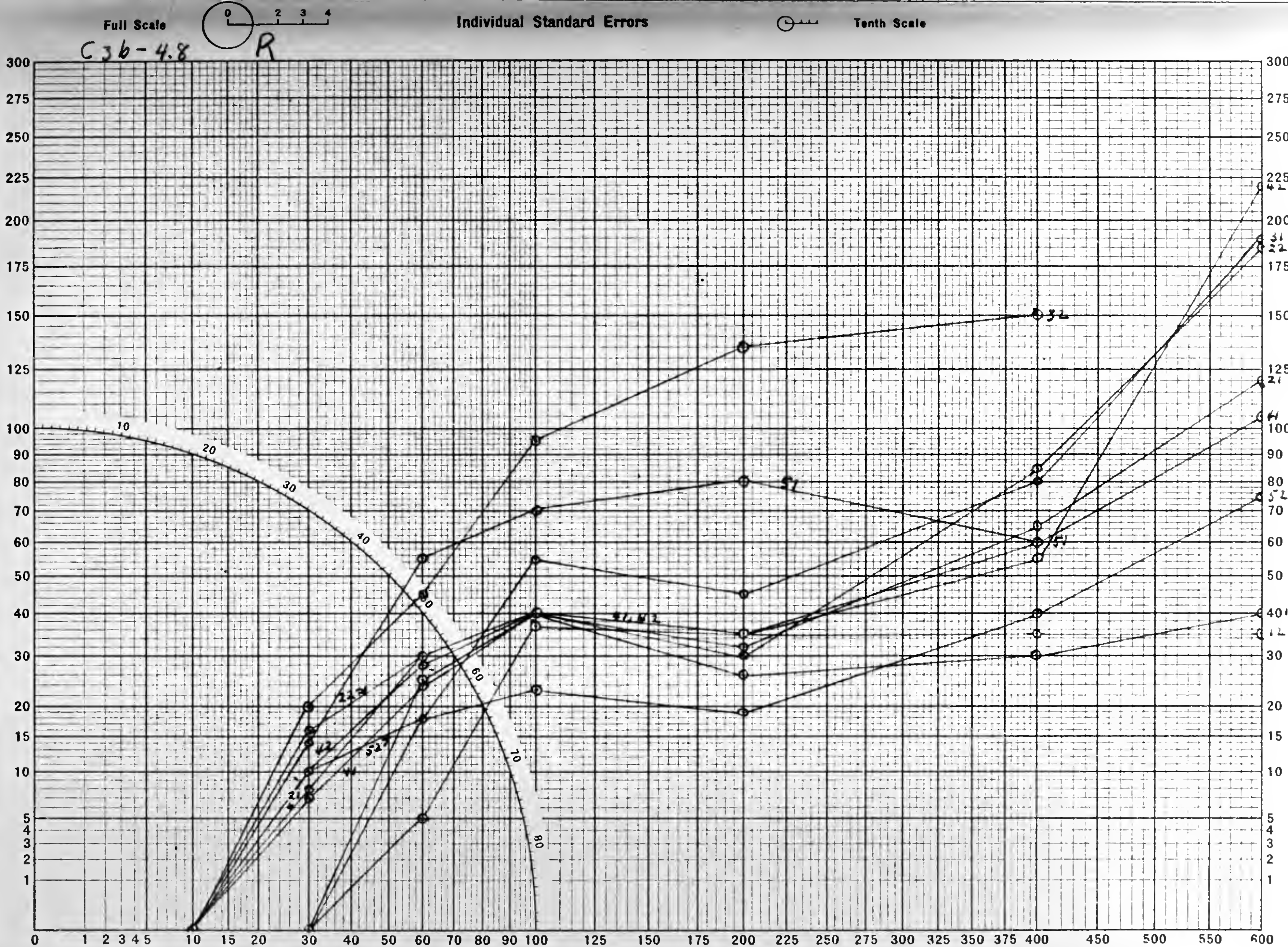
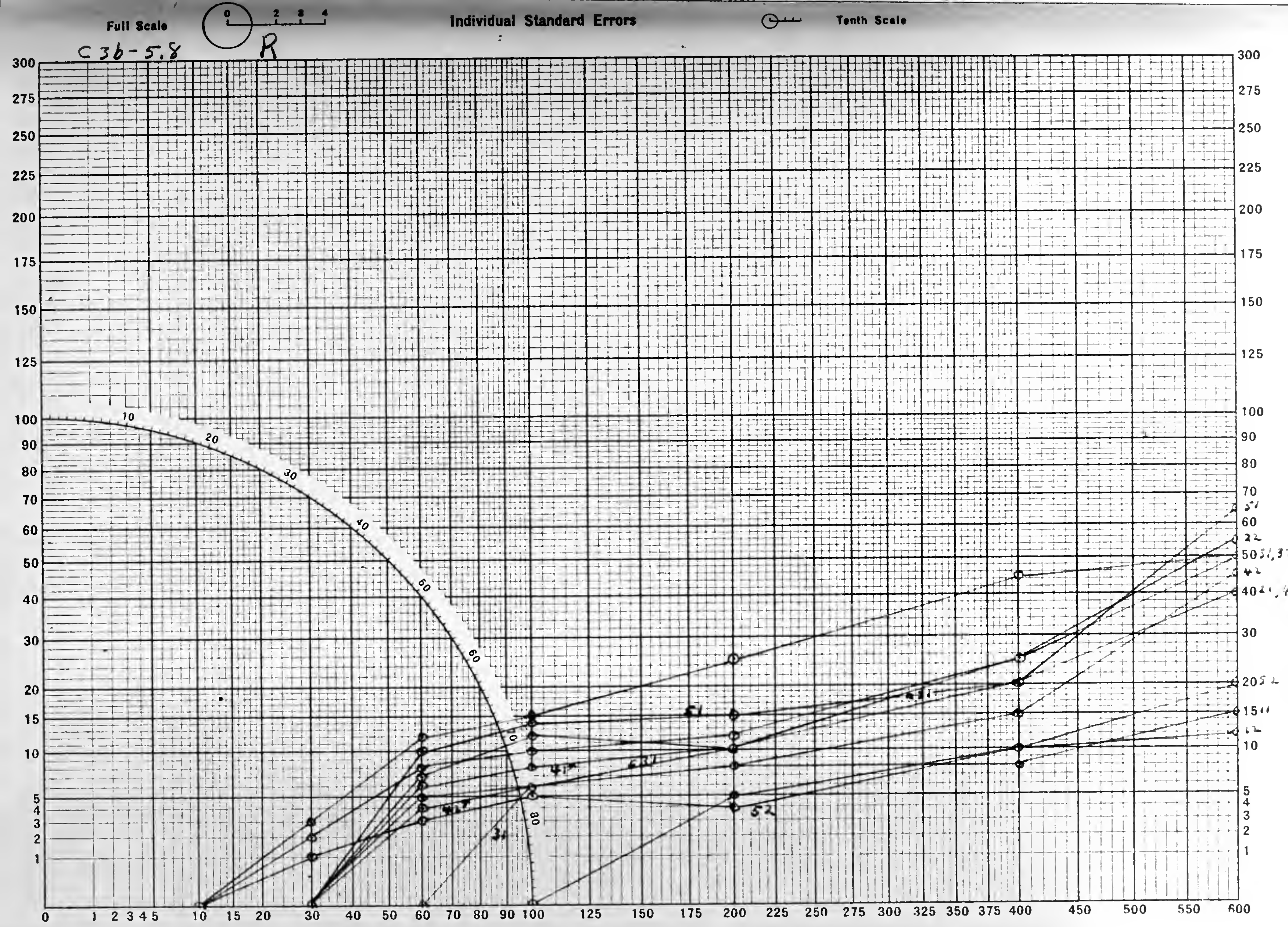
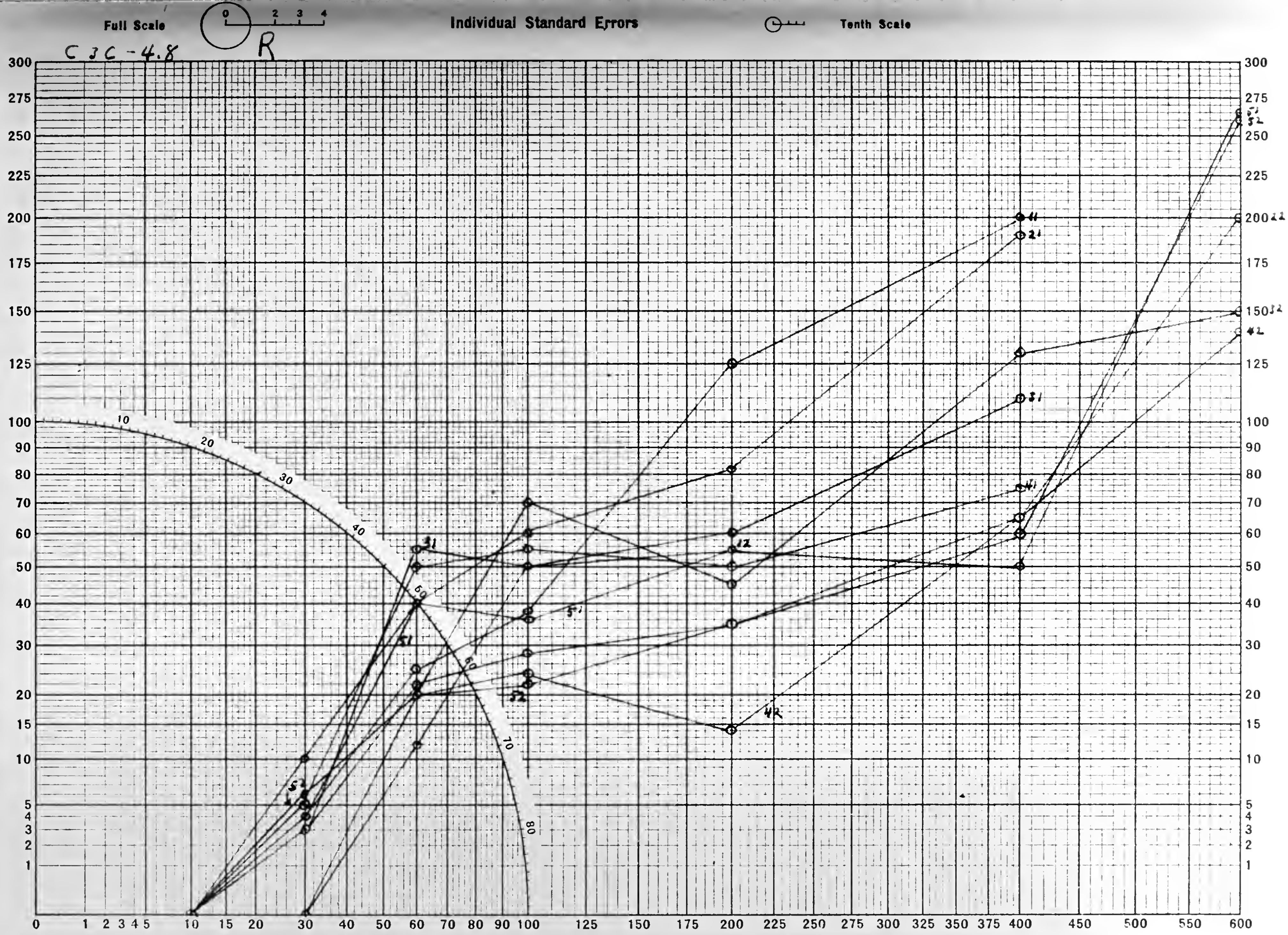
400
450
500
550
600



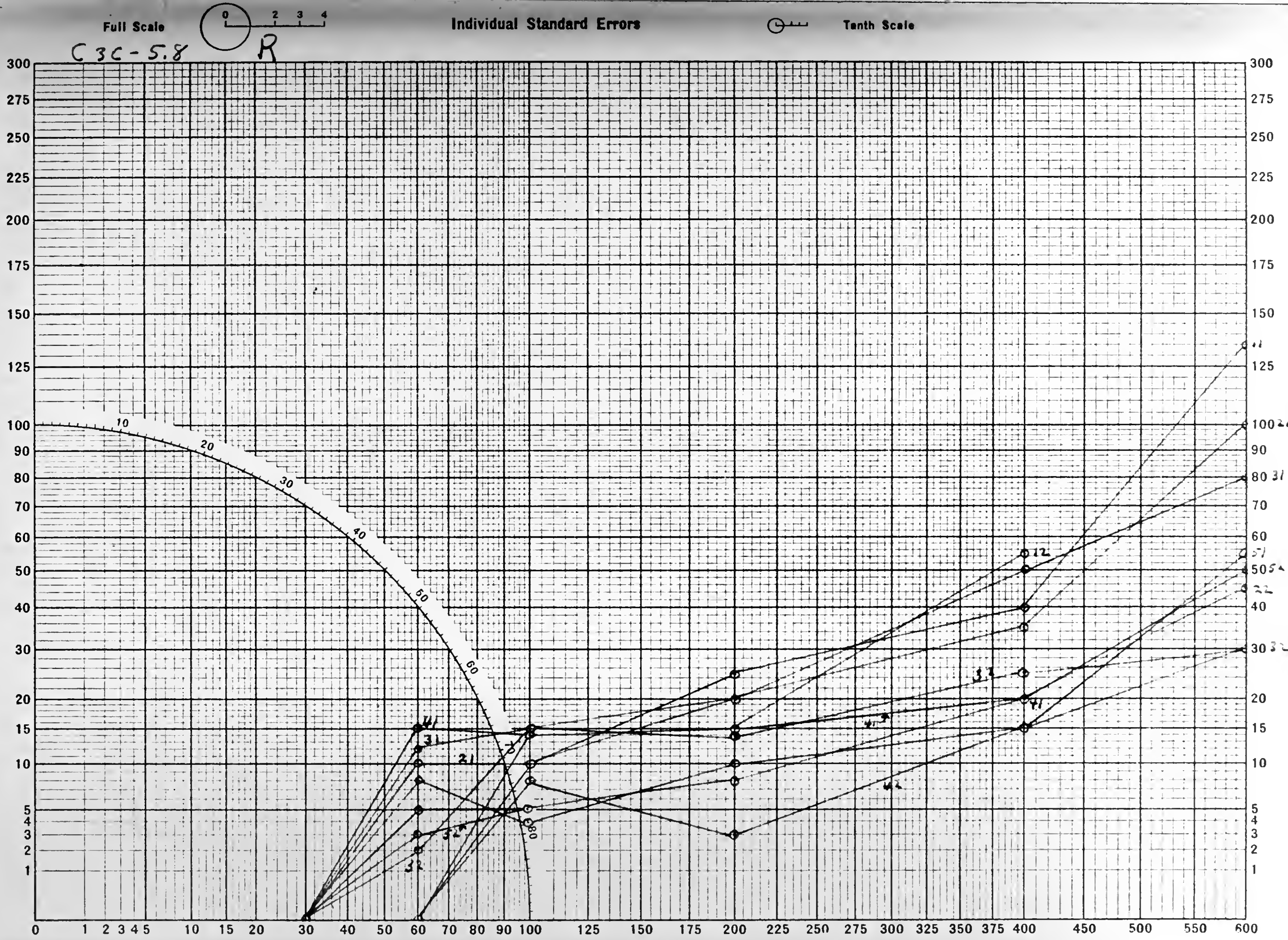
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3b-4.8
R



Full Scale
Individual Standard Errors
Tenth Scale
C3b-5.8
R



Full Scale
0 2 3 4
C 3C - 4.8
R
Individual Standard Errors
Tenth Scale



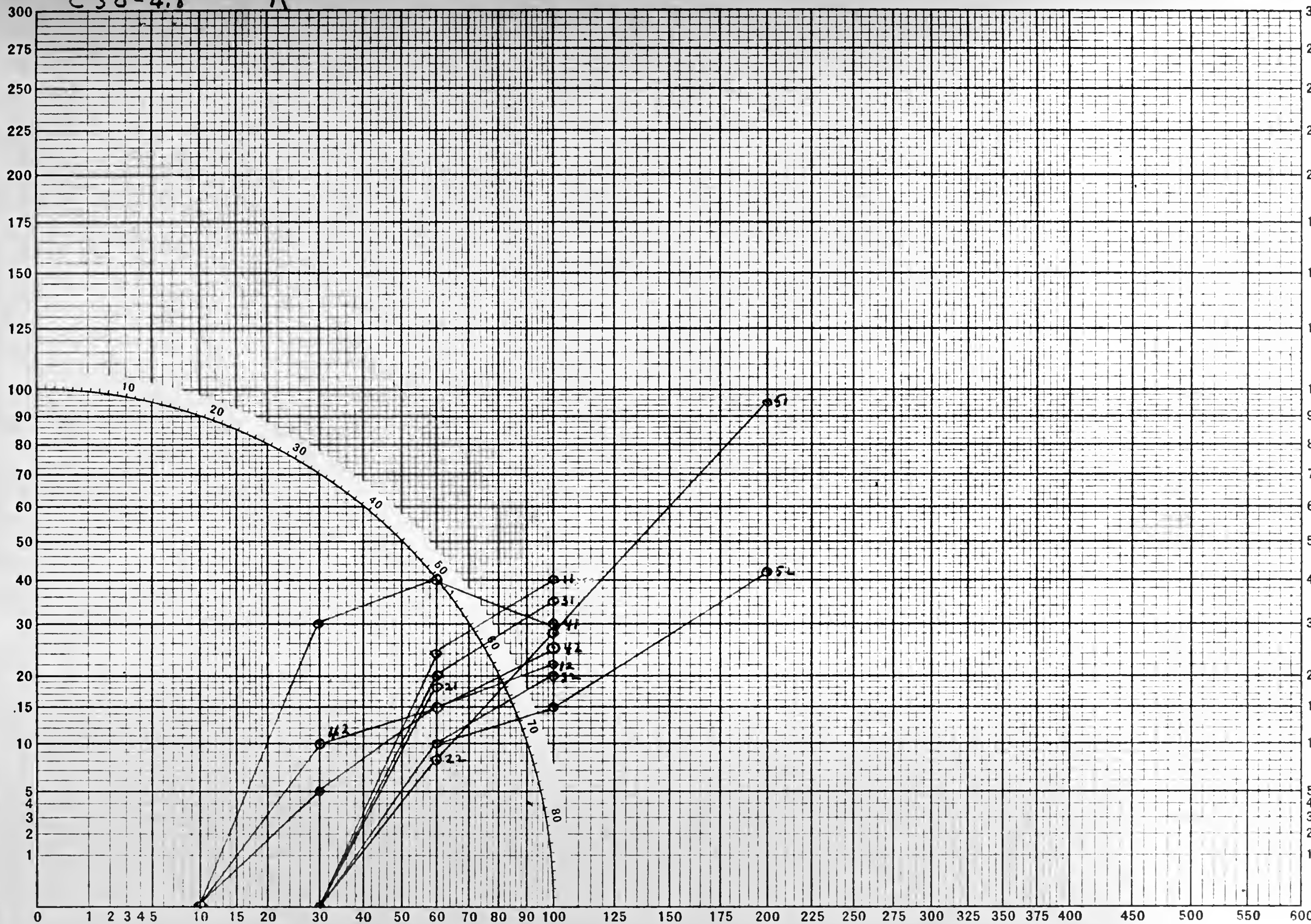
Full Scale
Individual Standard Errors
Tenth Scale
C 3C - 5.8
R

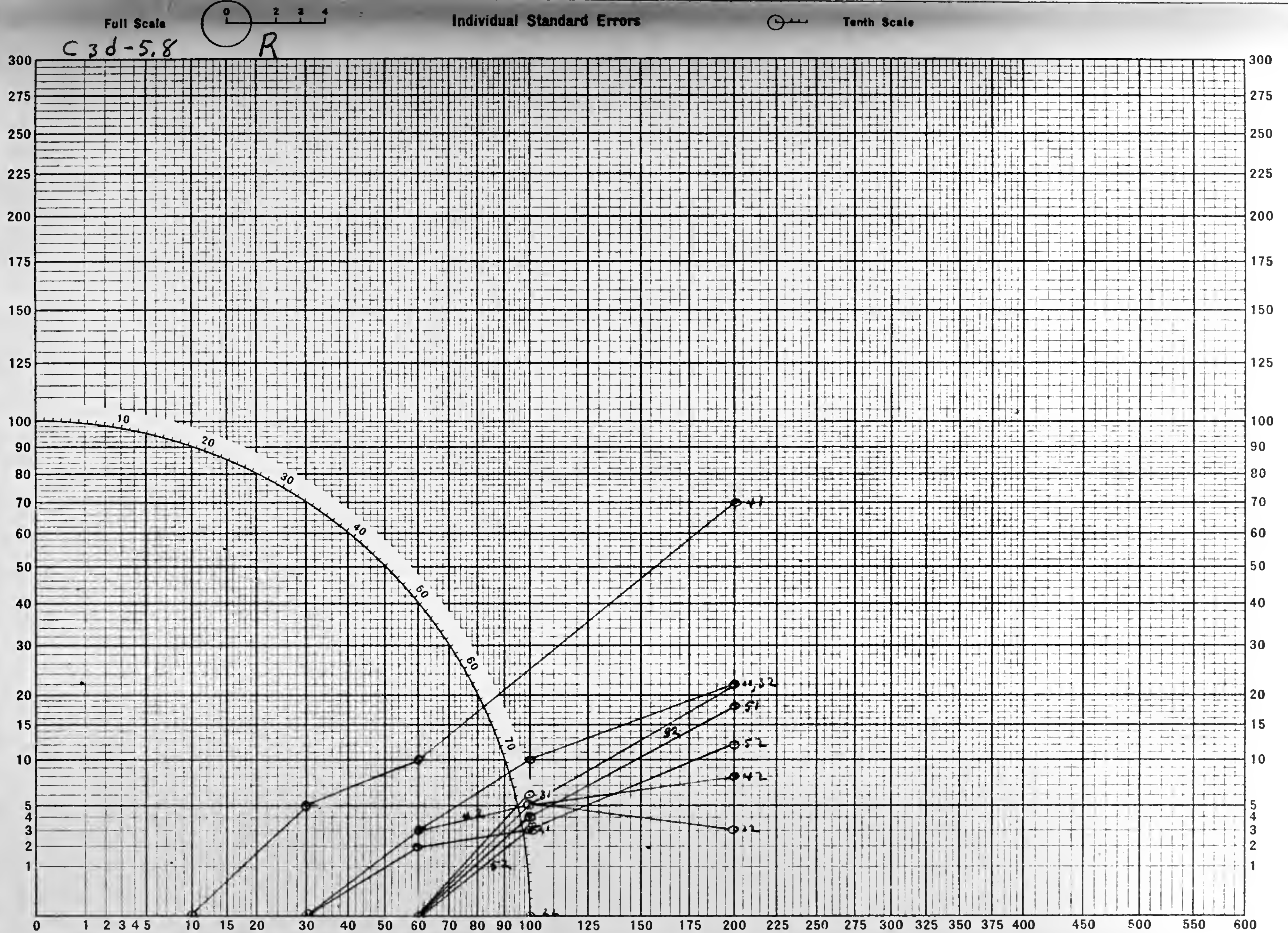
Full Scale

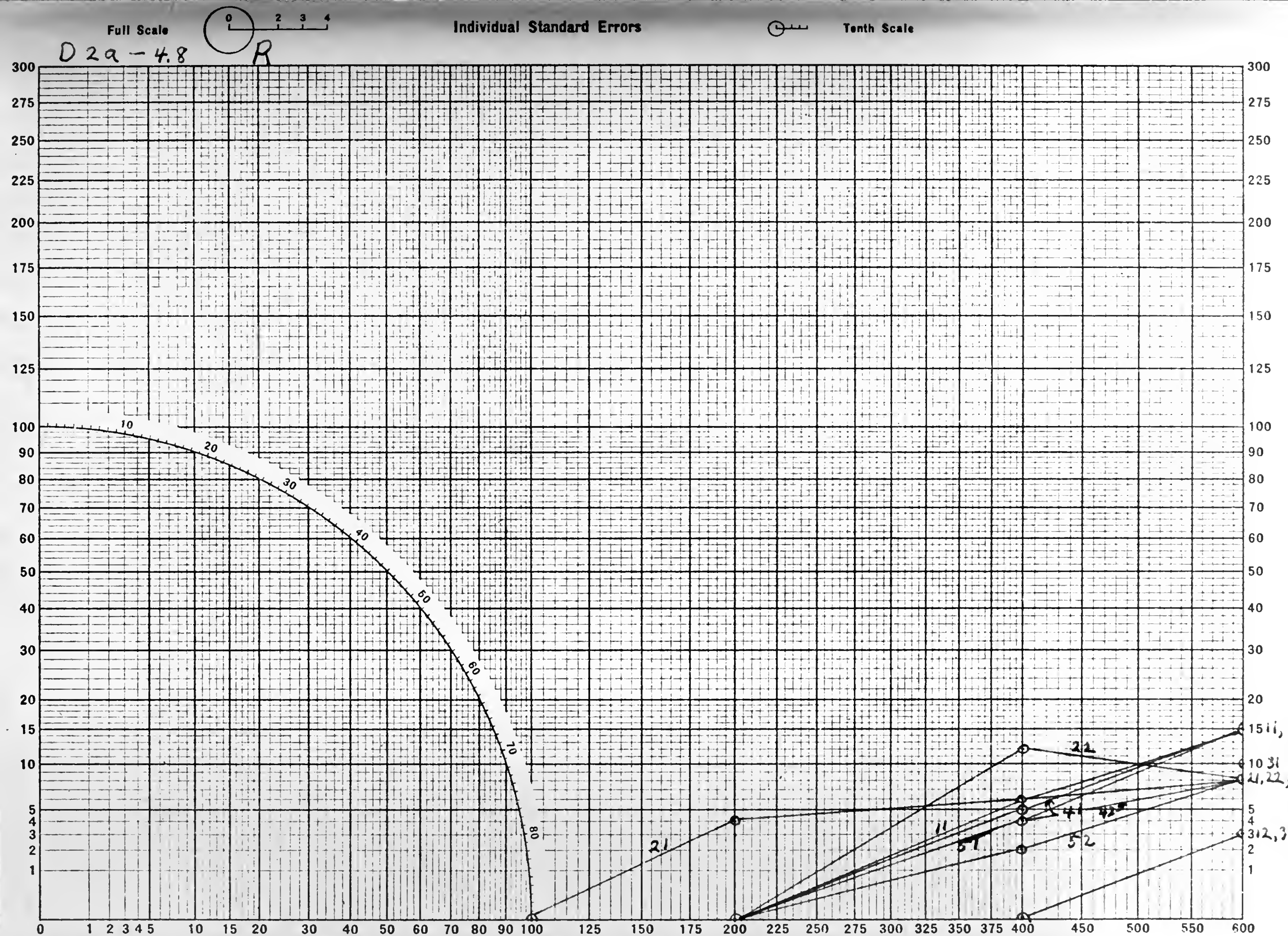
C 3d-4.8 R

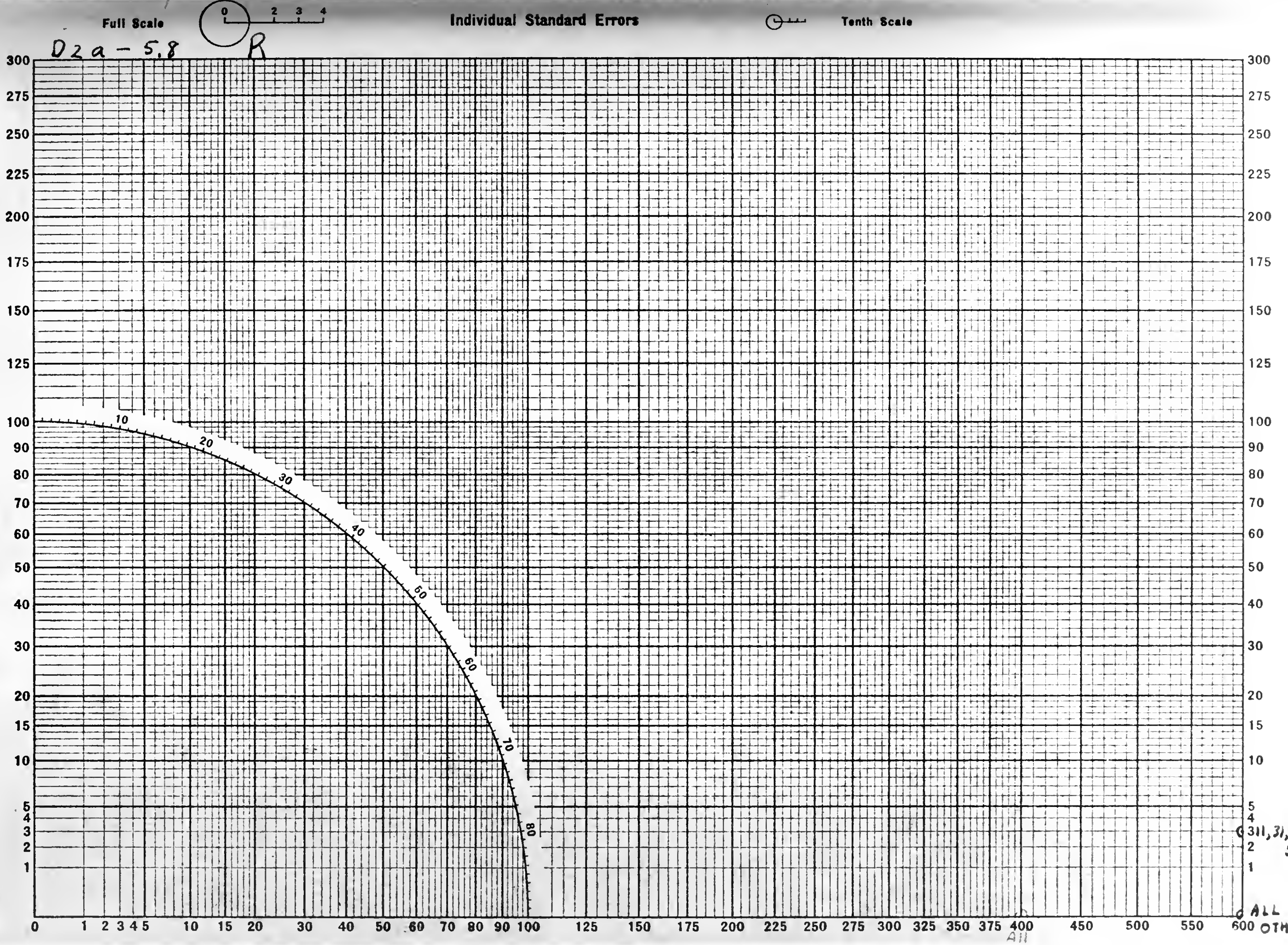
Individual Standard Errors

Tenth Scale




Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3d-5.8
R
41
11,32
51
52
42
12
92
31

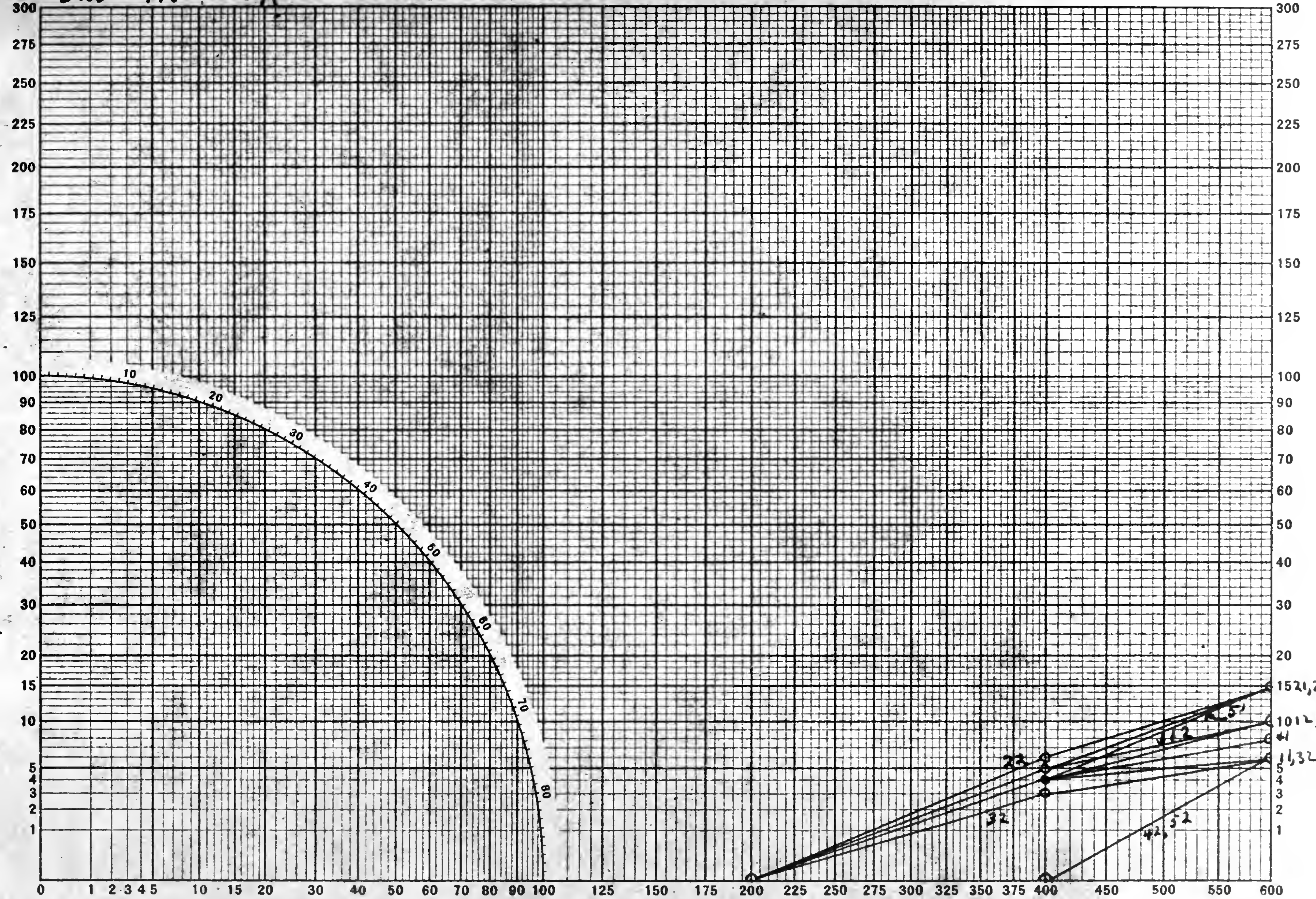

Full Scale
Individual Standard Errors
Tenth Scale
D2a - 4.8
R
21
22
11
41
42
51
52

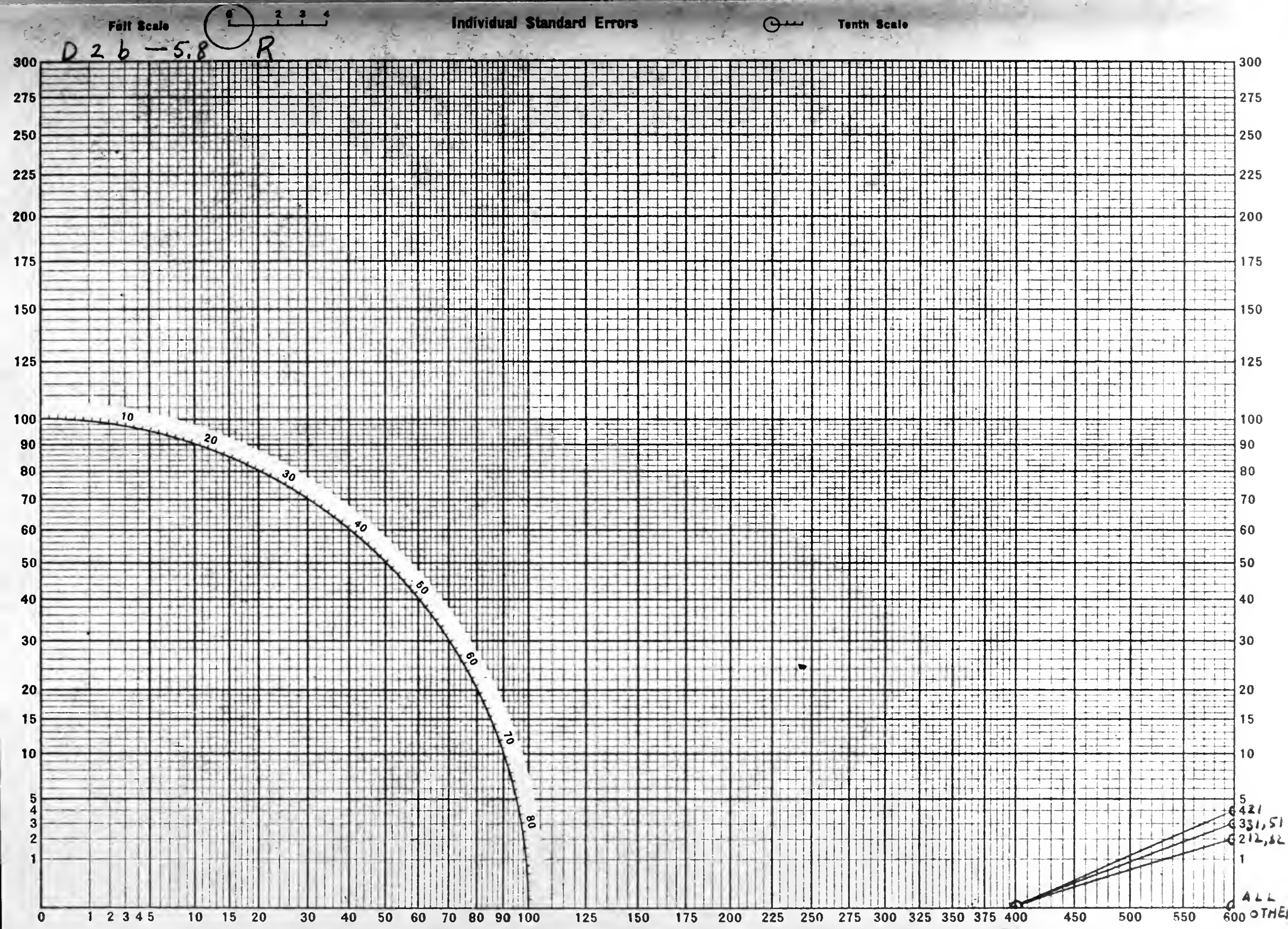


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2a - 5.8
R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10 15 20 30 40 50 60 70 80 90 100
125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80
311, 31, 4
ALL
OTHE
All

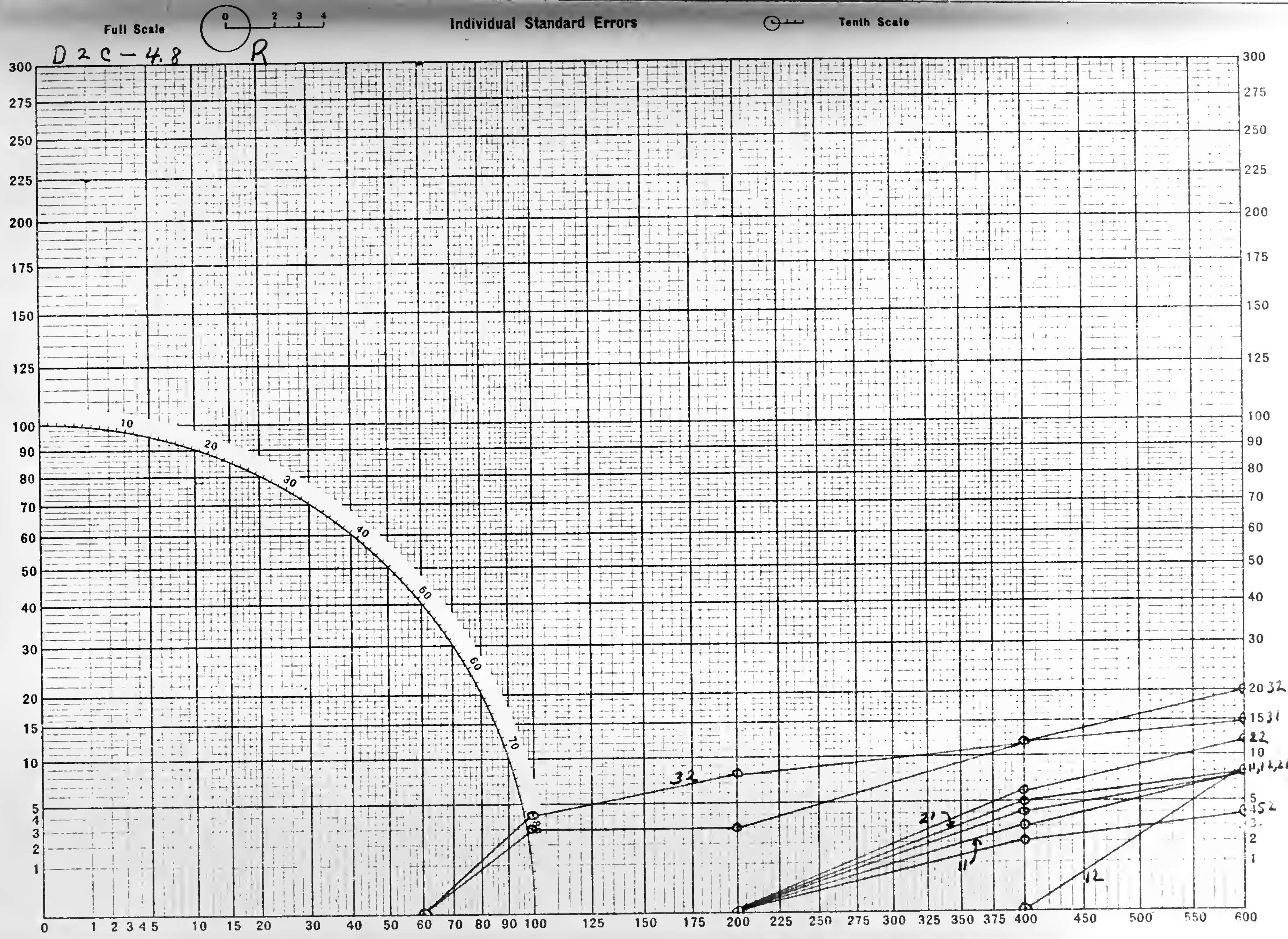
Full Scale   Individual Standard Errors   Tenth Scale

D2b - 4.8





Felt Scale
Individual Standard Errors
Tenth Scale
D 2 b — 5.8
R
421
331, 51
212, 82
ALL OTHE



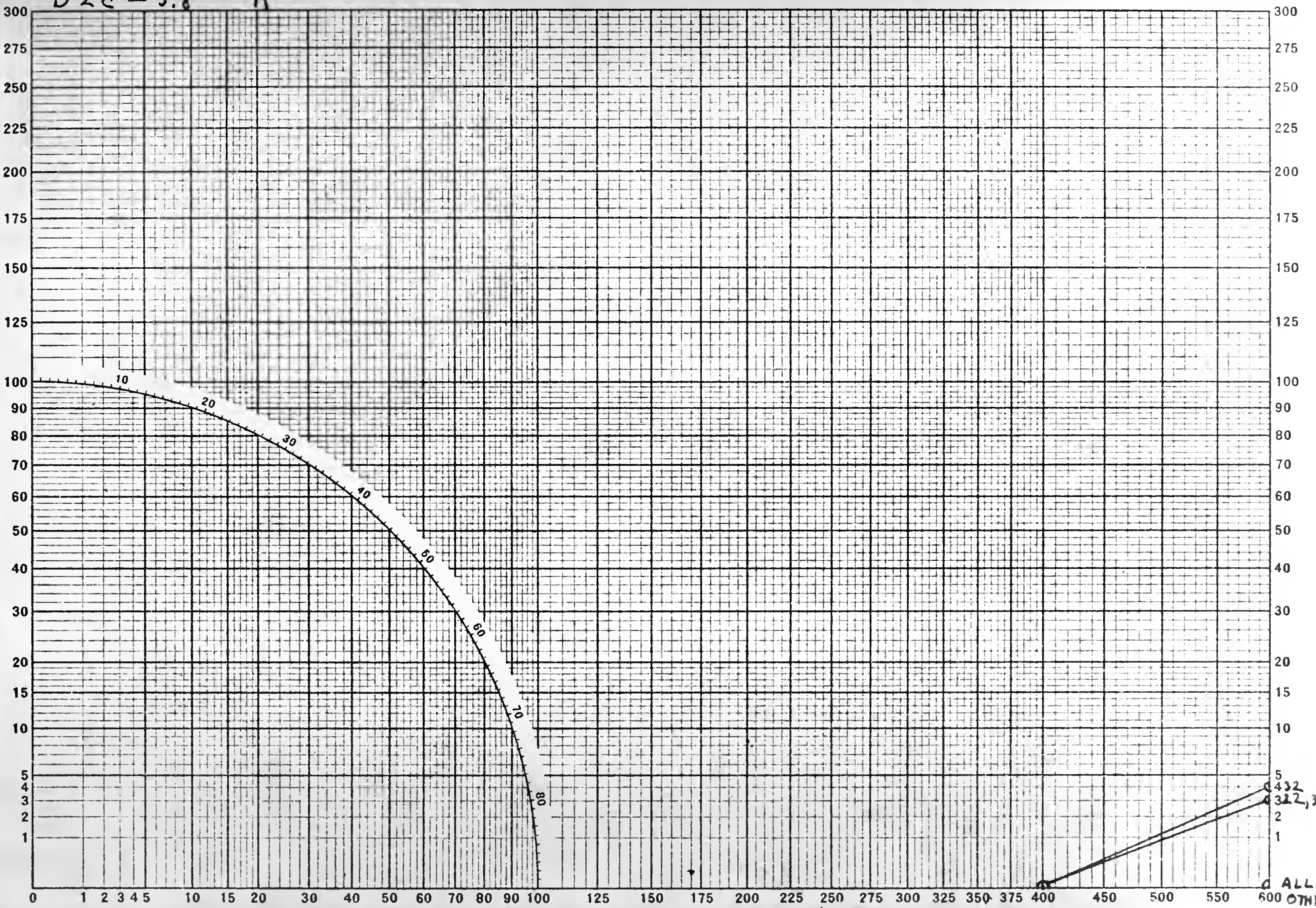
Full Scale
Tenth Scale
Individual Standard Errors
D 2 C - 4.8
R
32
21
11
12

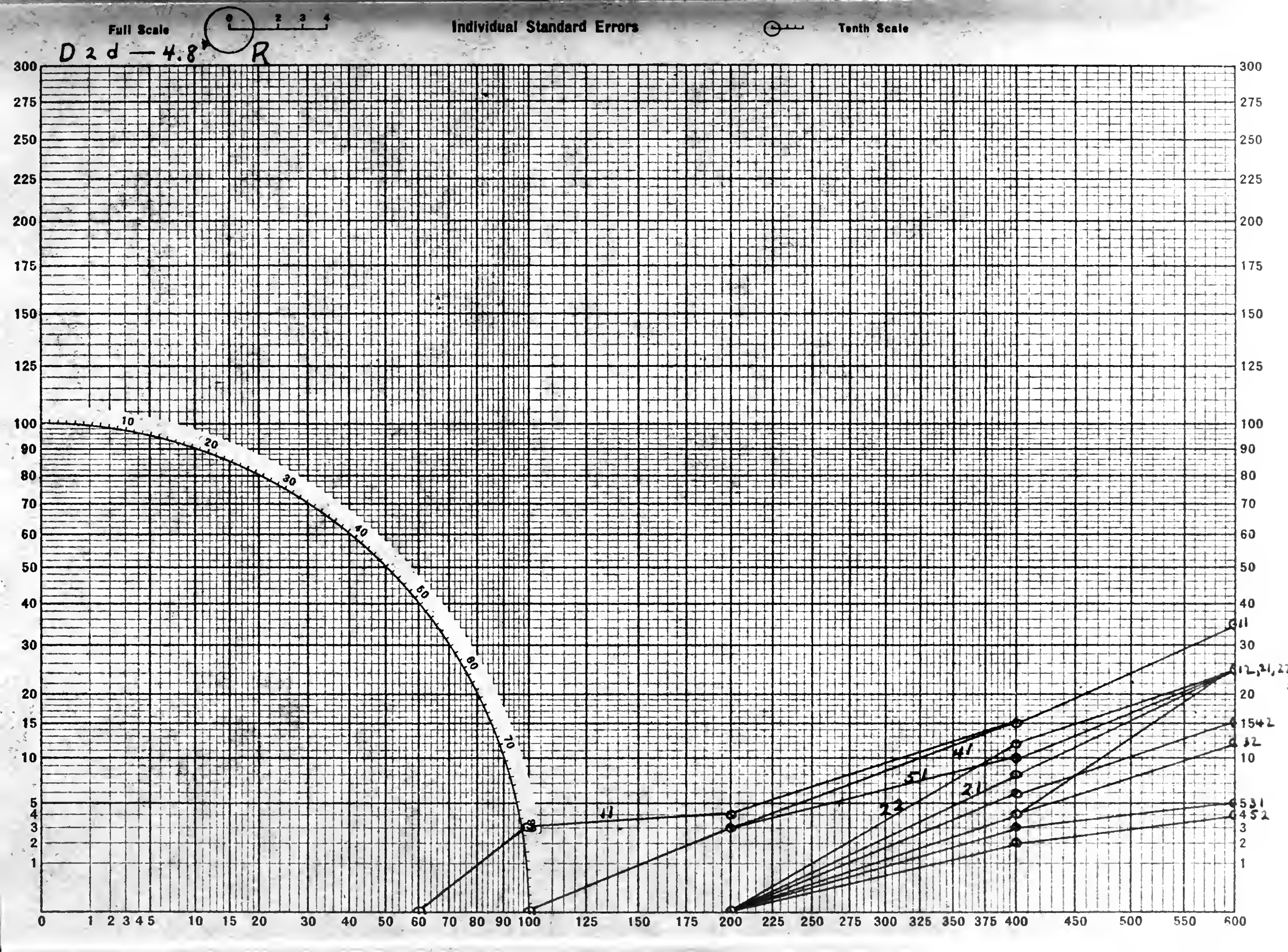
Full Scale

Individual Standard Errors

Tenth Scale

D 2 c — 5.8 R

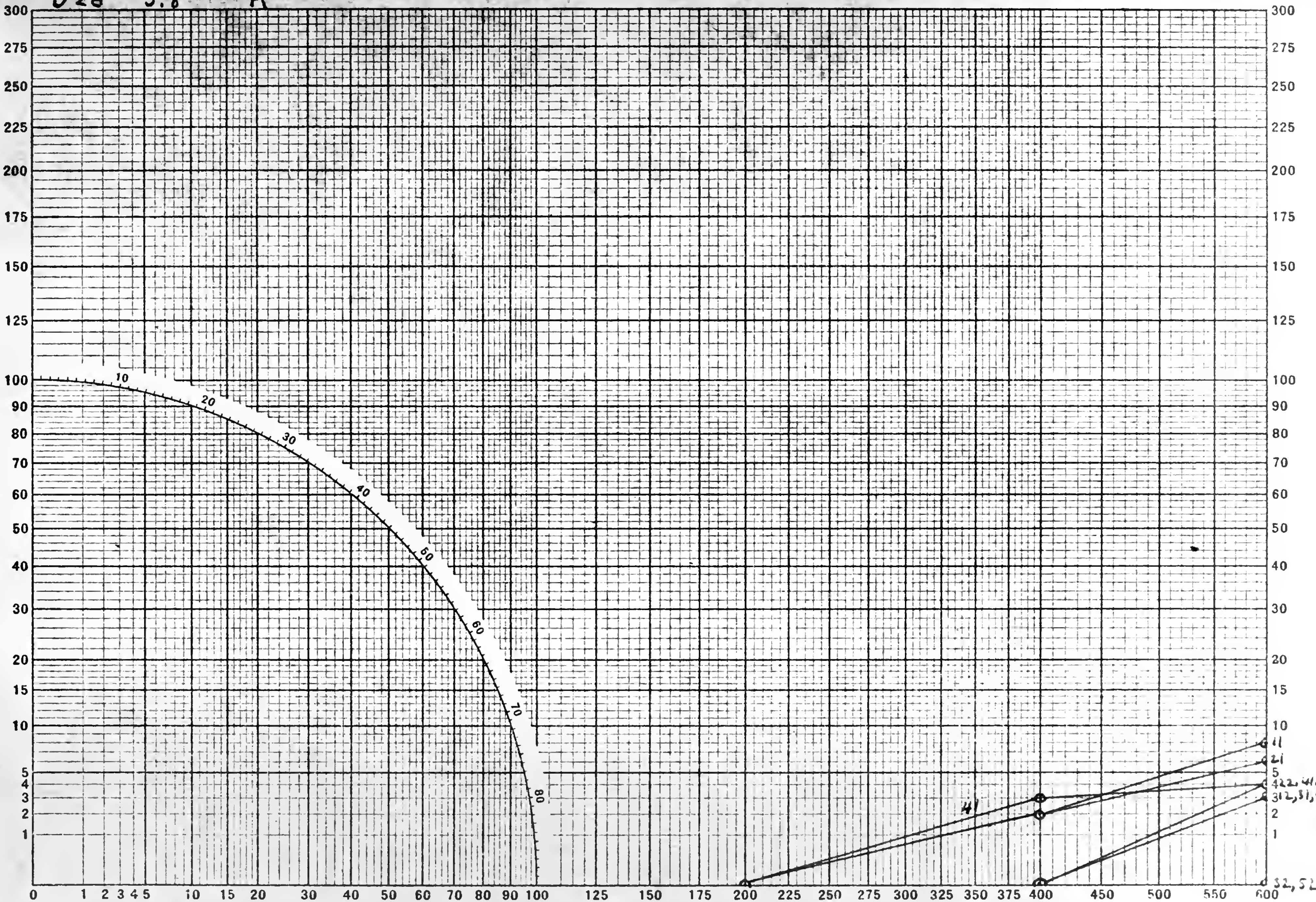


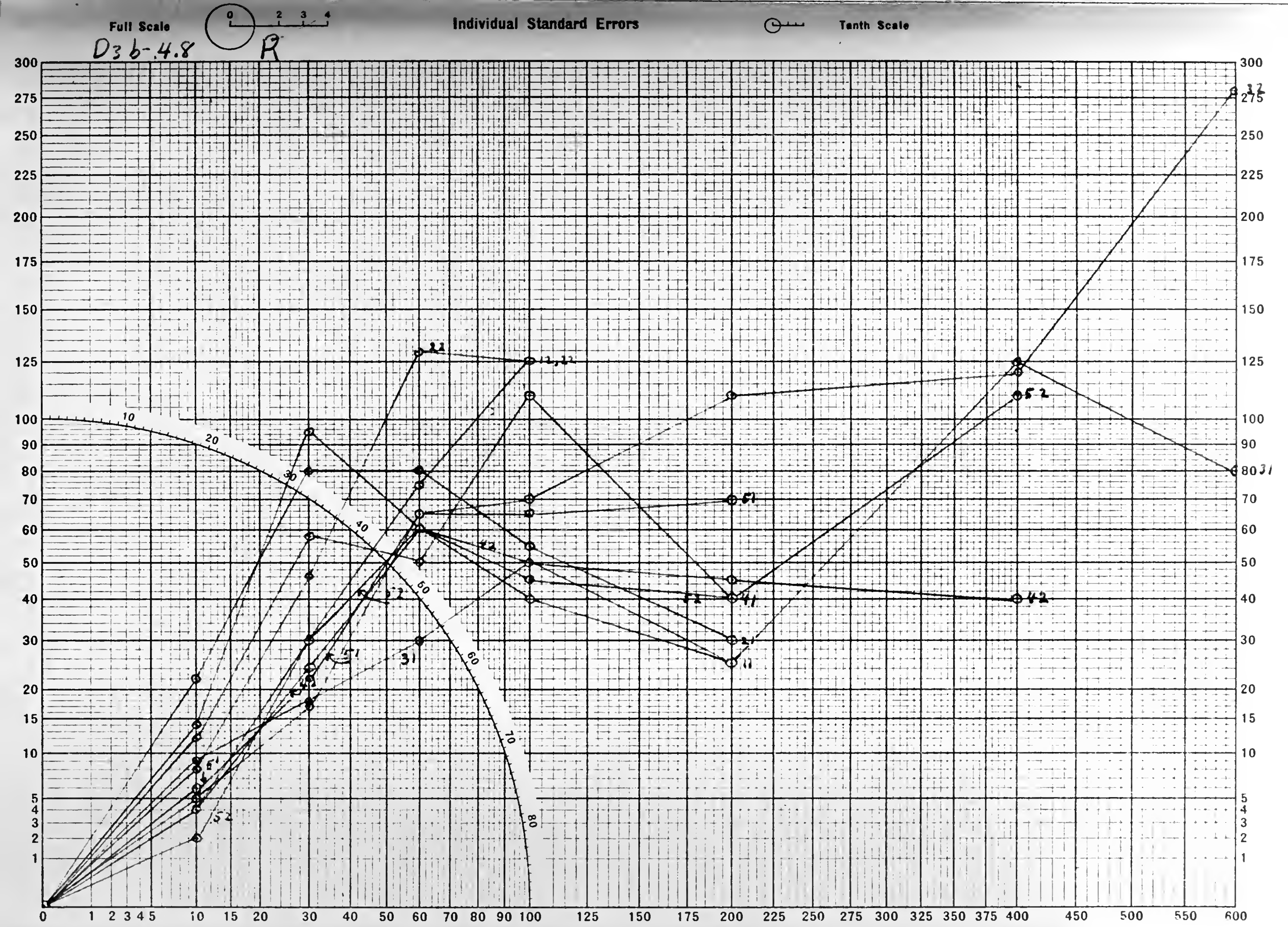


Full Scale
Individual Standard Errors
Tenth Scale
D 2 d — 4.8 R
11
51
41
22
21
11
12, 21, 22
1542
32
531
452

Full Scale Individual Standard Errors Tenth Scale

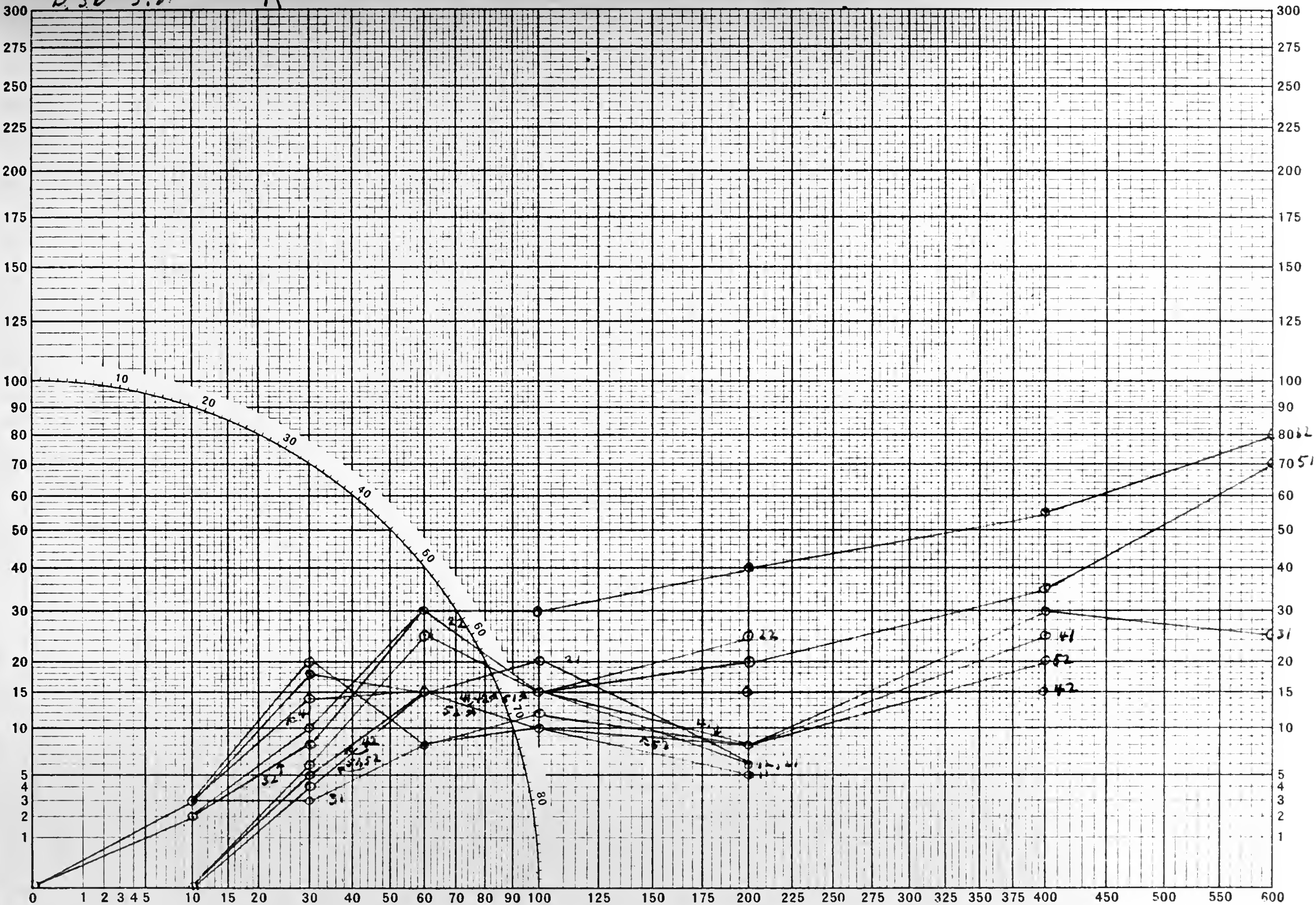
D2d - 5.8 R




Full Scale
D3 b-4.8
R
Individual Standard Errors
Tenth Scale

Full Scale 0 2 3 4 **Individual Standard Errors** Tenth Scale

D36-5.8 R

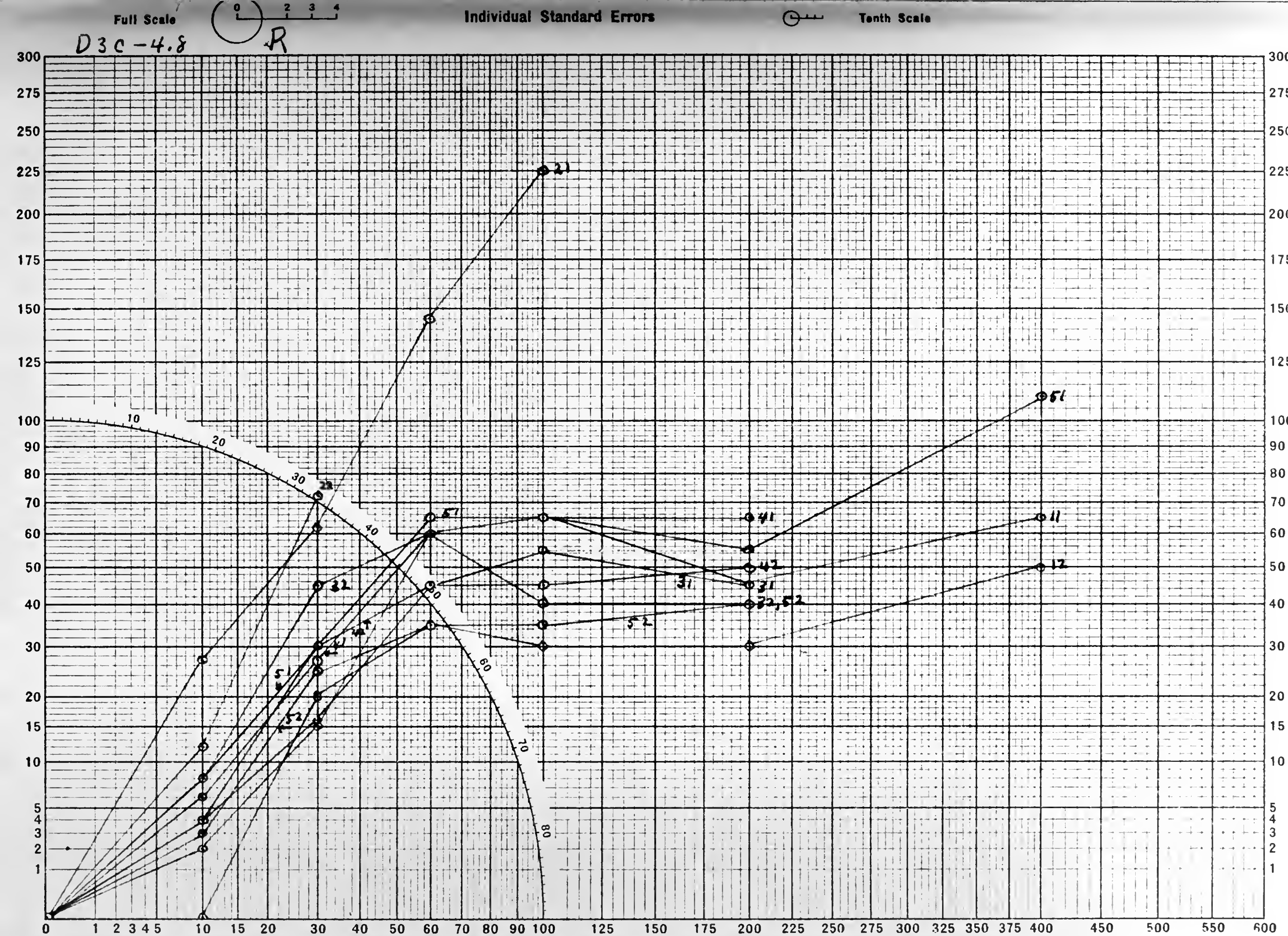


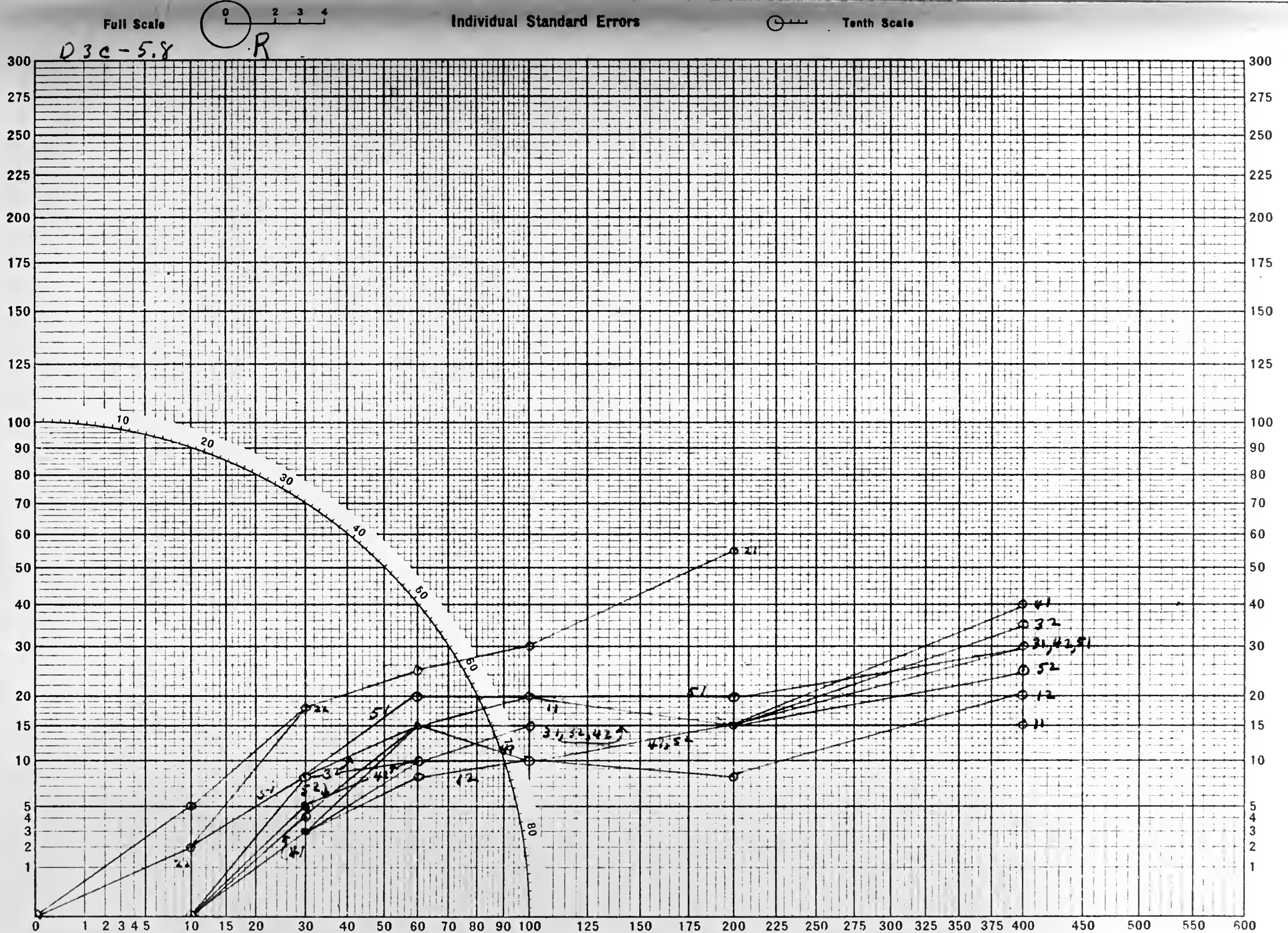
Full Scale

D3C-4.8 R

Individual Standard Errors

Tenth Scale




Full Scale
Individual Standard Errors
Tenth Scale
D3c-5.8
R
21
41
32
31,42,51
52
12
11
51
31,32,42
41,52
22
32
42
12

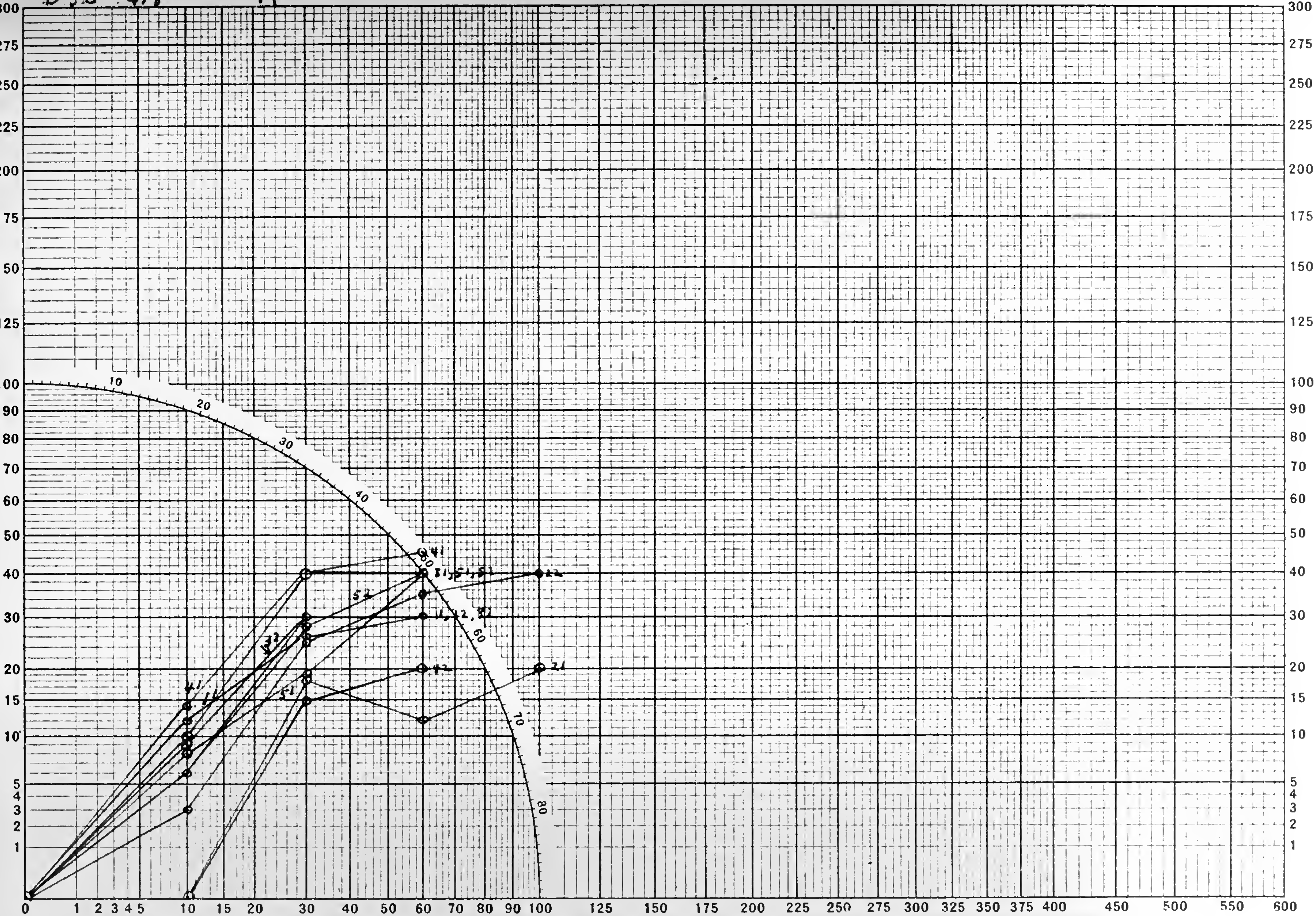
Full Scale

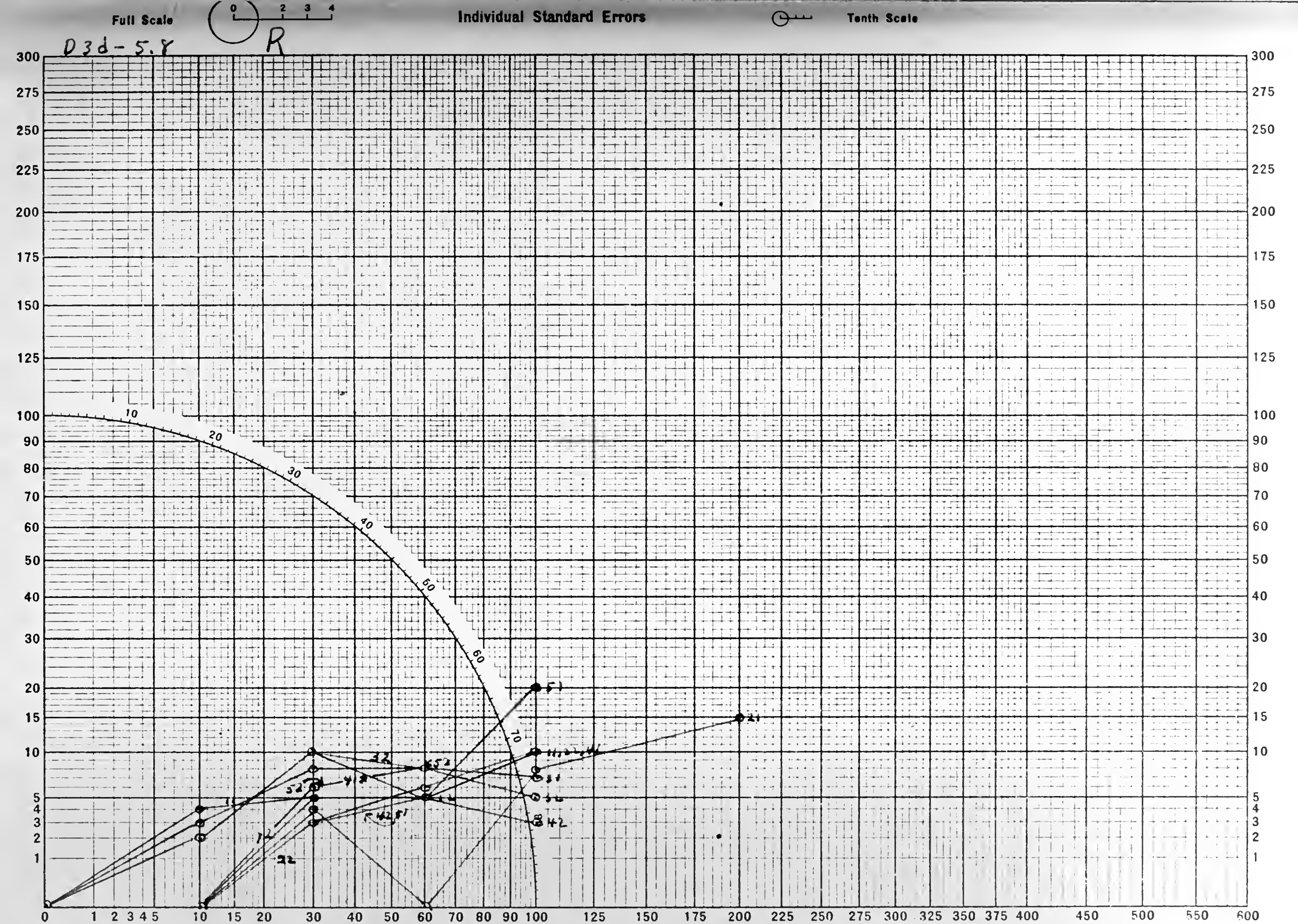
Individual Standard Errors

Tenth Scale

D 3 d - 4.8

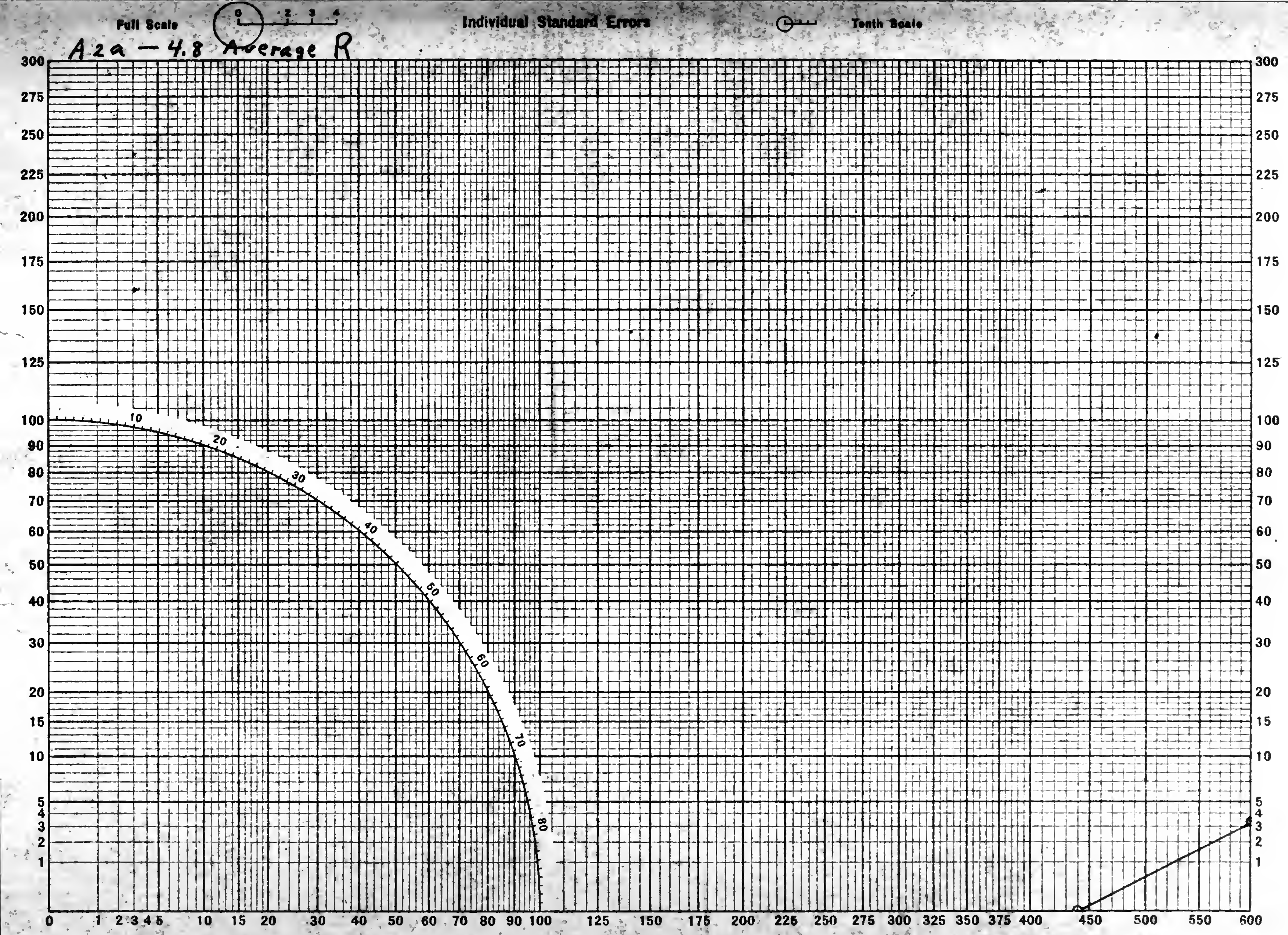
R





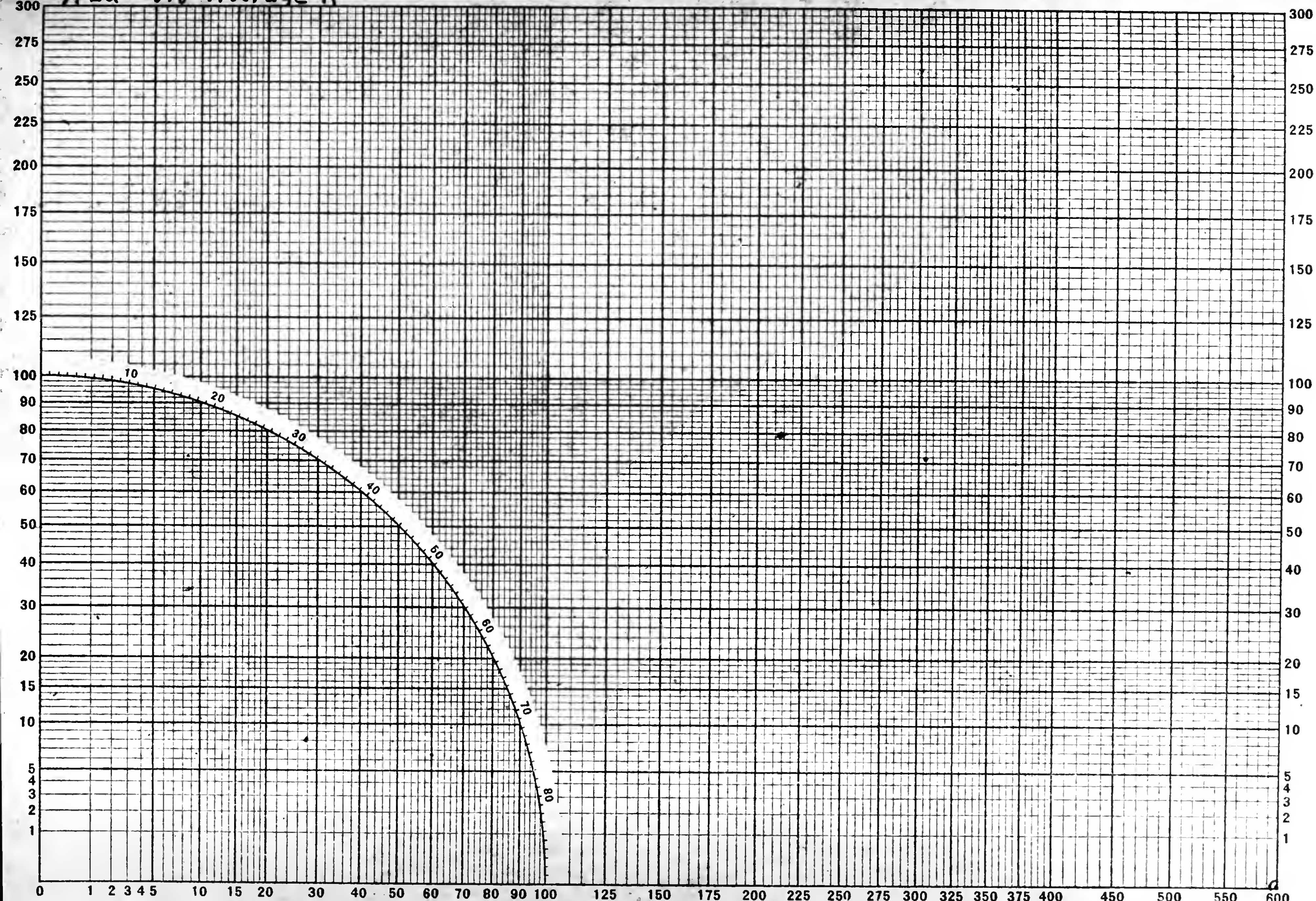
Full Scale
0 2 3 4
D3d-5.8
R
Individual Standard Errors
Tenth Scale

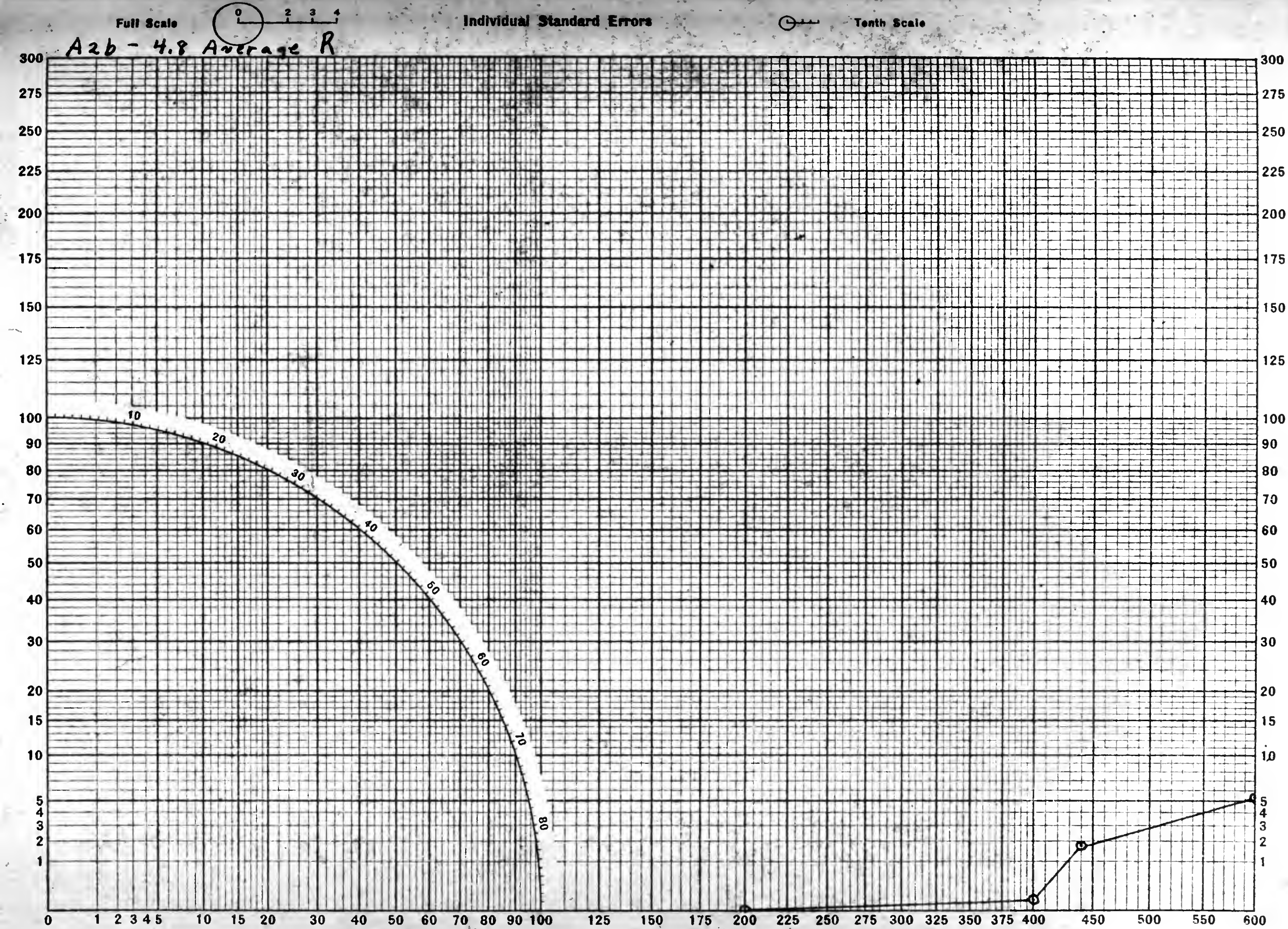
AVERAGE RESISTANCE, SINGLE GROUP


Full Scale
0 1 2 3 4
Individual Standard Errors
Tenth Scale
A2a — 4.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
10 20 30 40 50 60 70 80
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600

Full Scale 0 2 3 4 **Individual Standard Errors** Tenth Scale

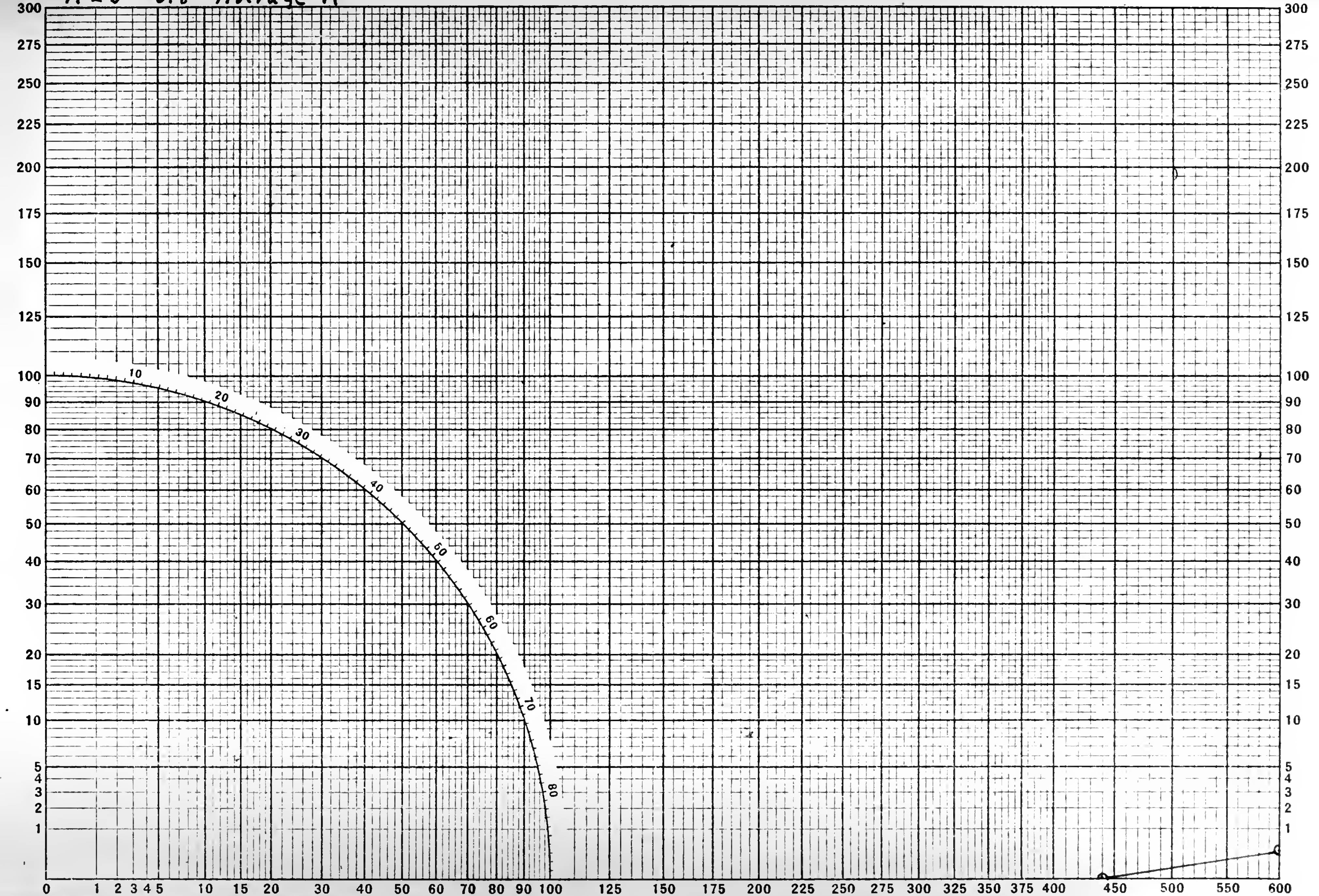
A2a — 5.8 Average R




Full Scale
Individual Standard Errors
Tenth Scale
A2b - 4.8 Average R
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
10 20 30 40 50 60 70 80

Full Scale — Individual Standard Errors — Tenth Scale

A 2b — 5.8 Average R

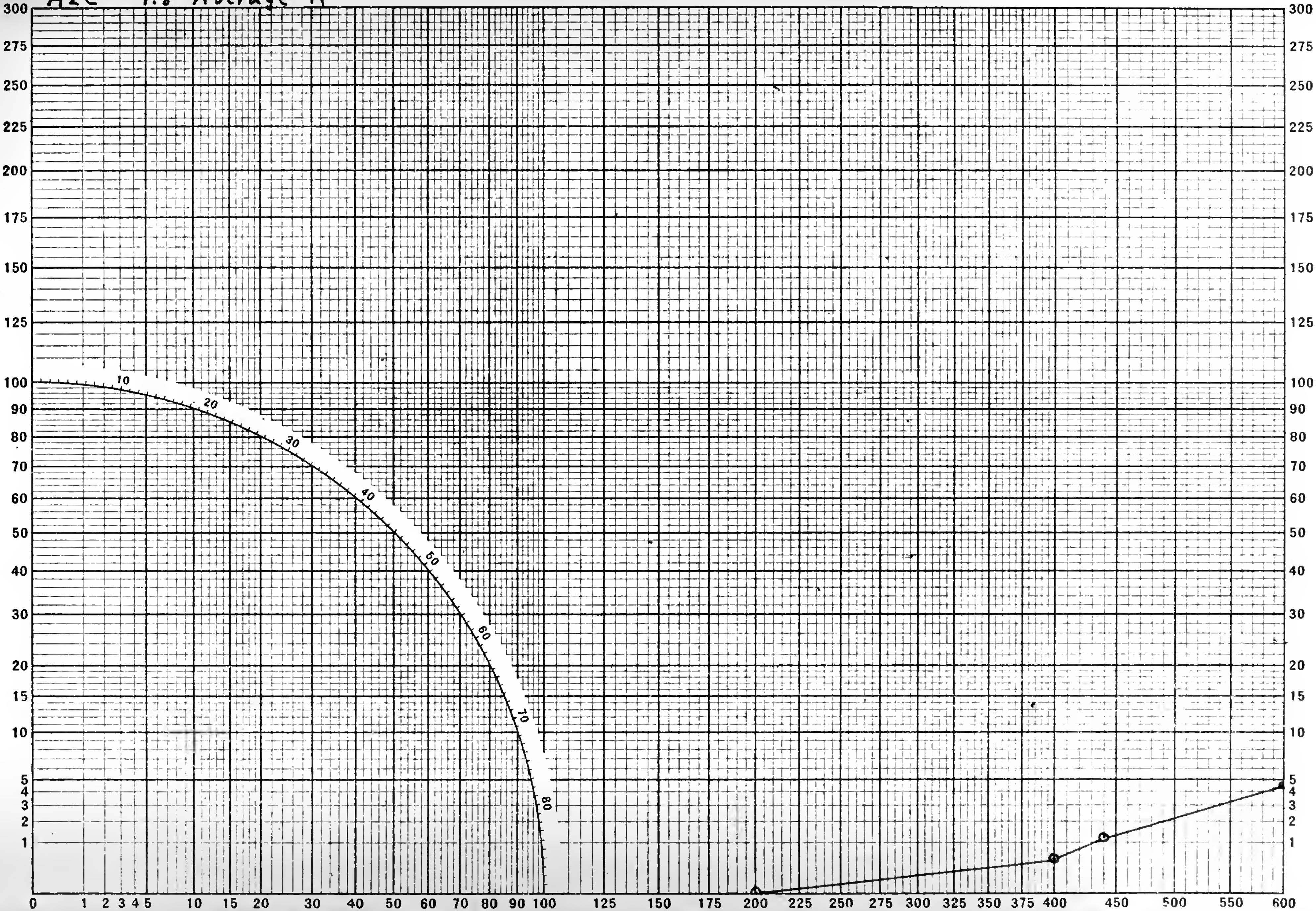


Full Scale

Individual Standard Errors

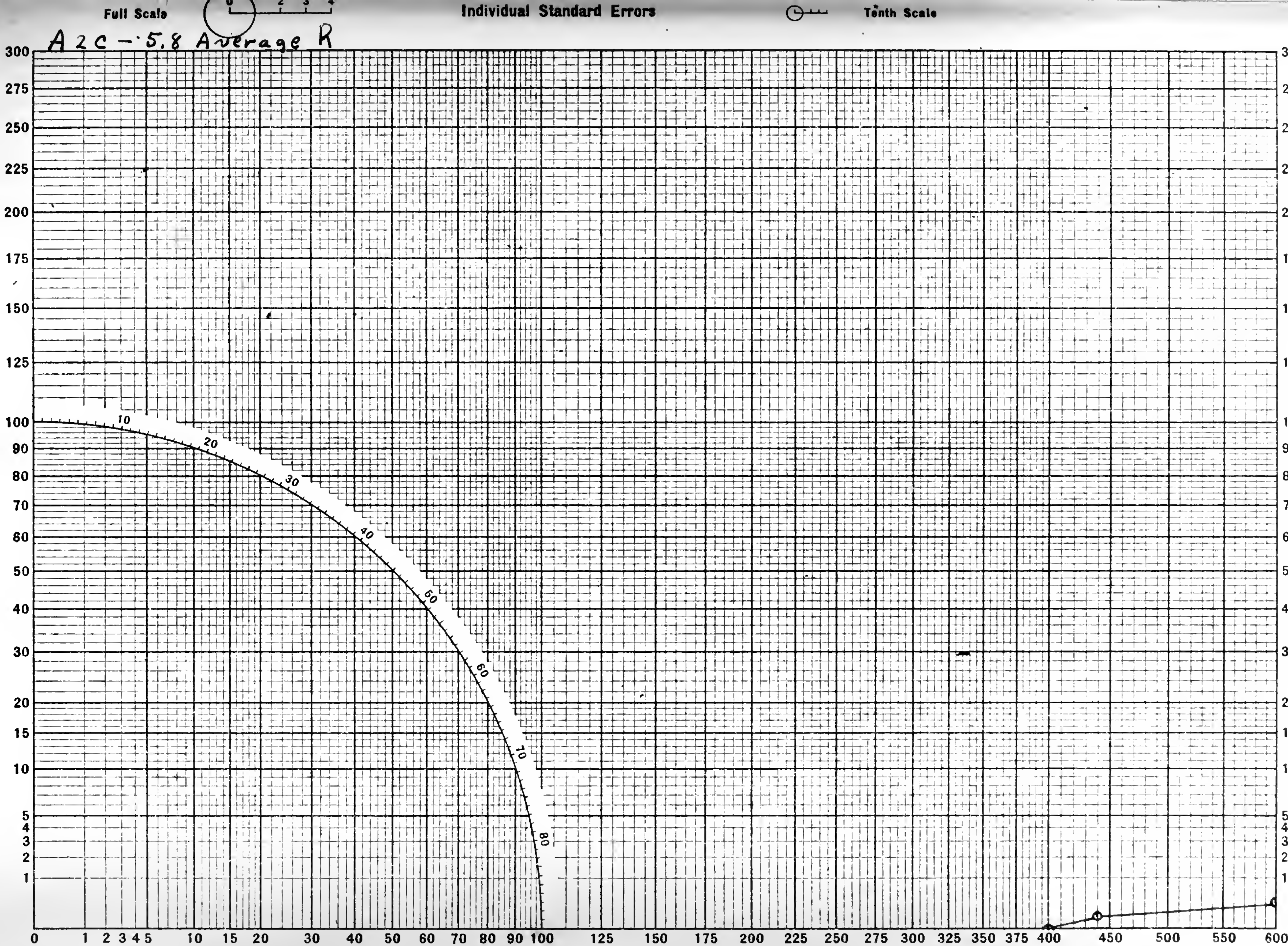
Tenth Scale

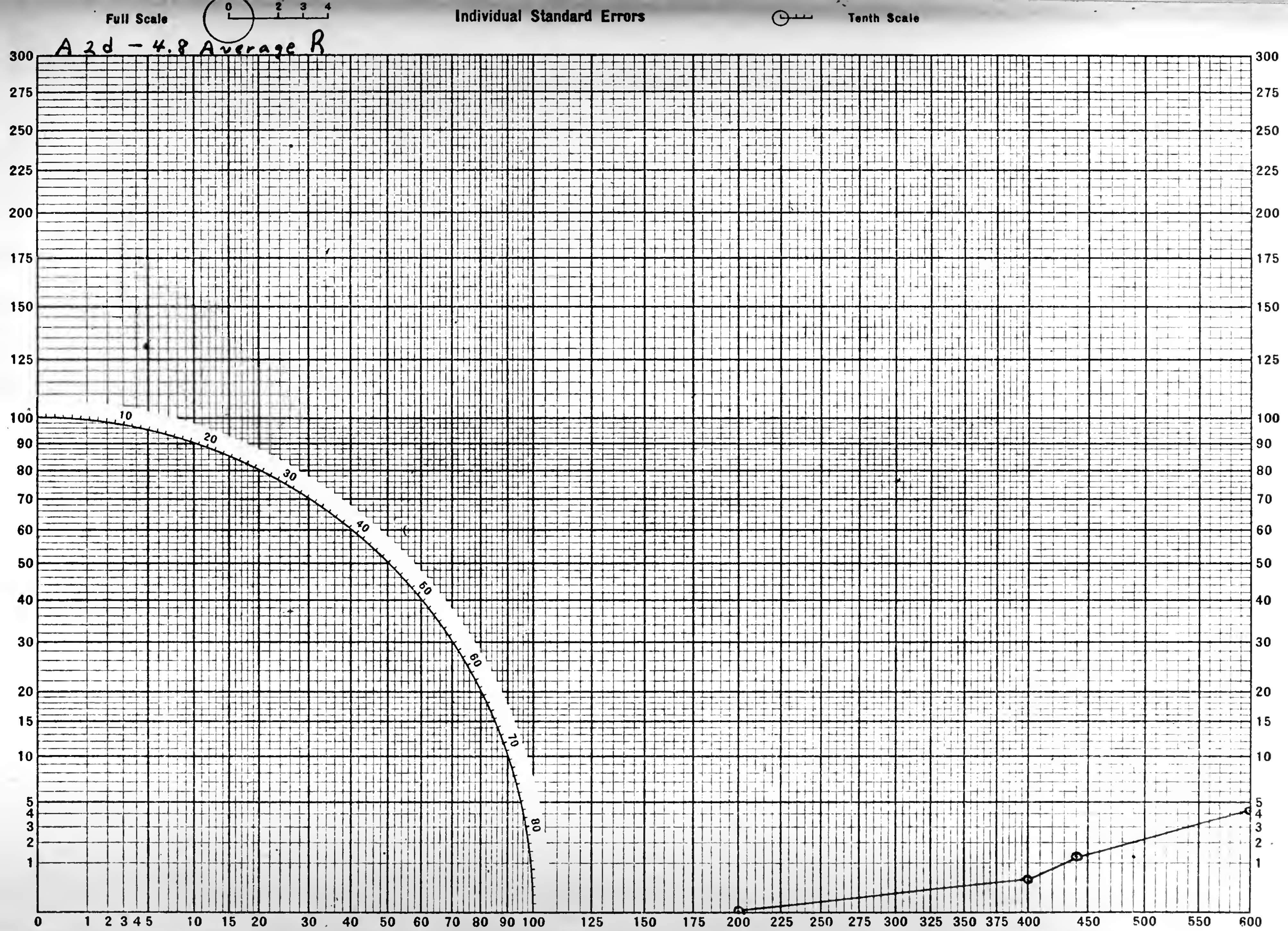
A2C - 4.8 Average R



Full Scale Individual Standard Errors Tenth Scale

A 2c - 5.8 Average R





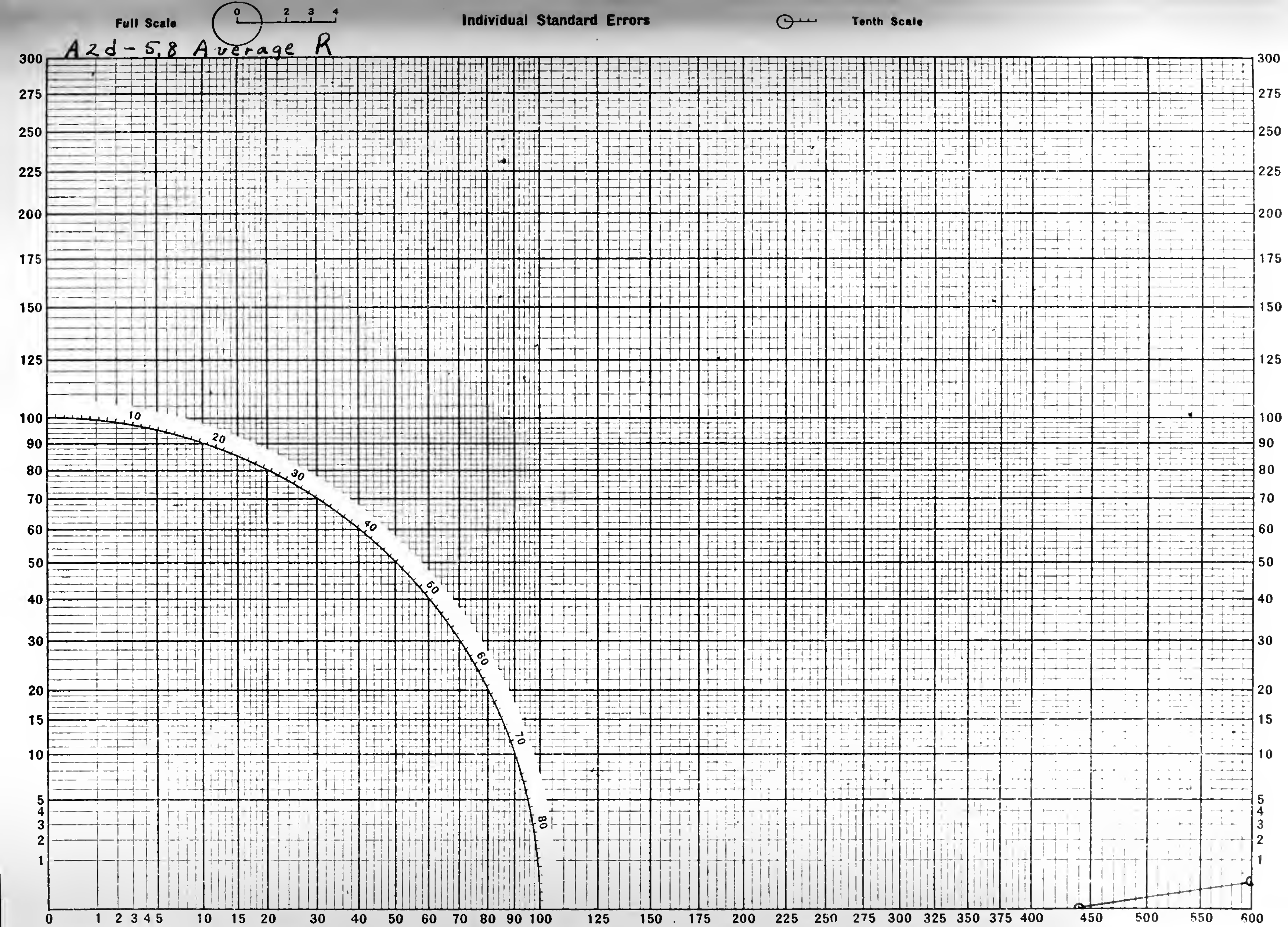
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2d - 4.8 Average R

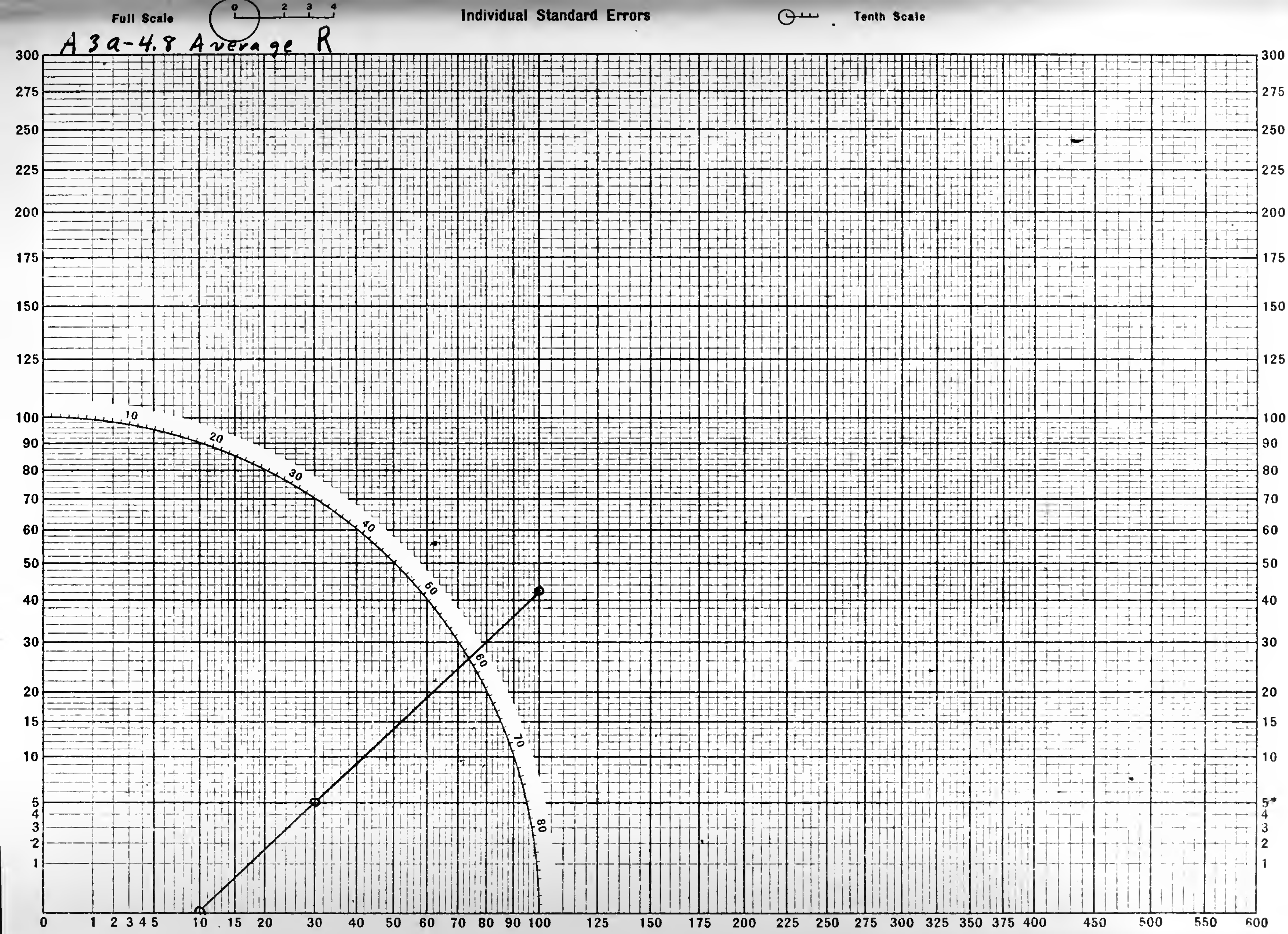
Full Scale

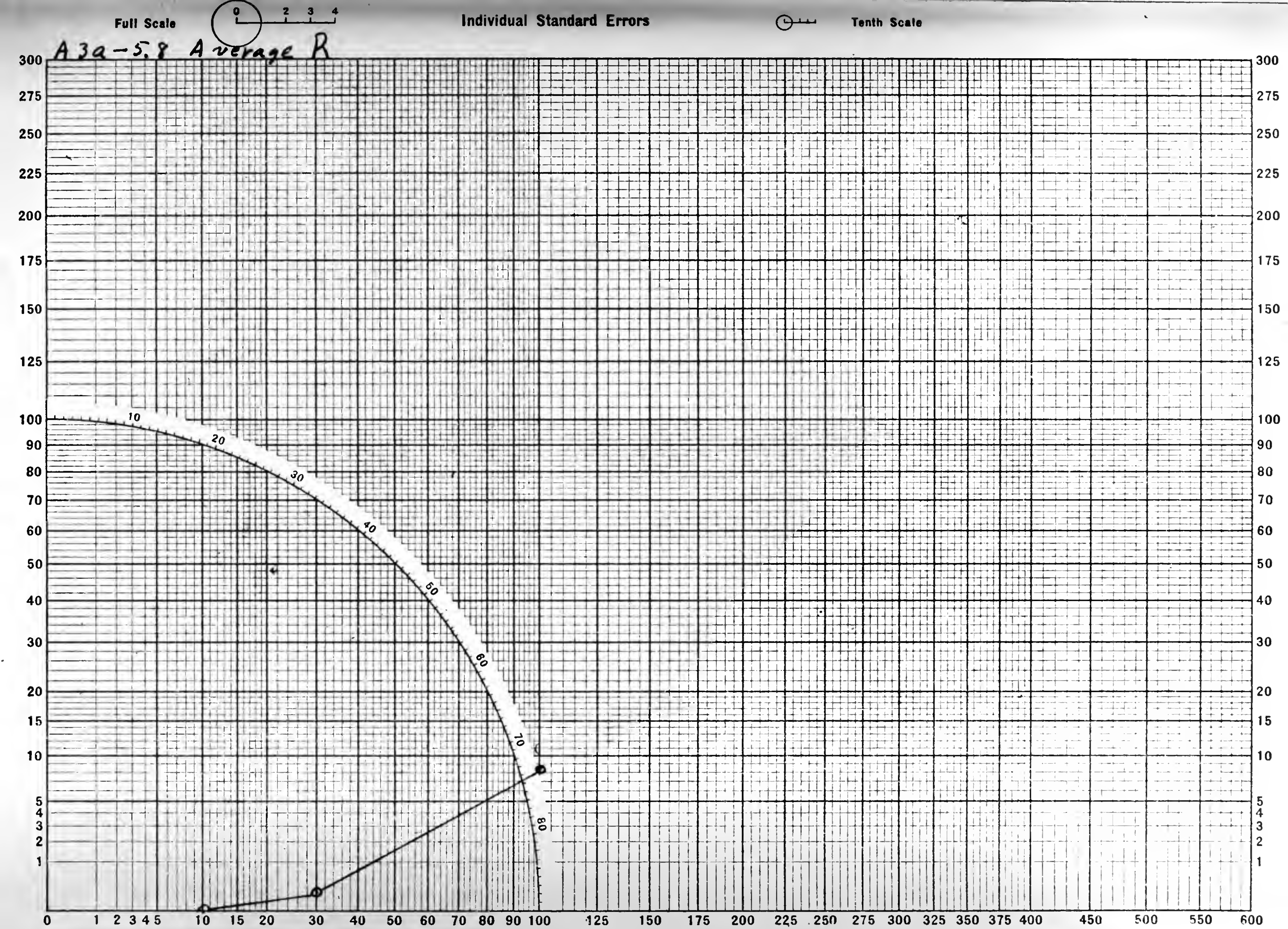
Individual Standard Errors

Tenth Scale

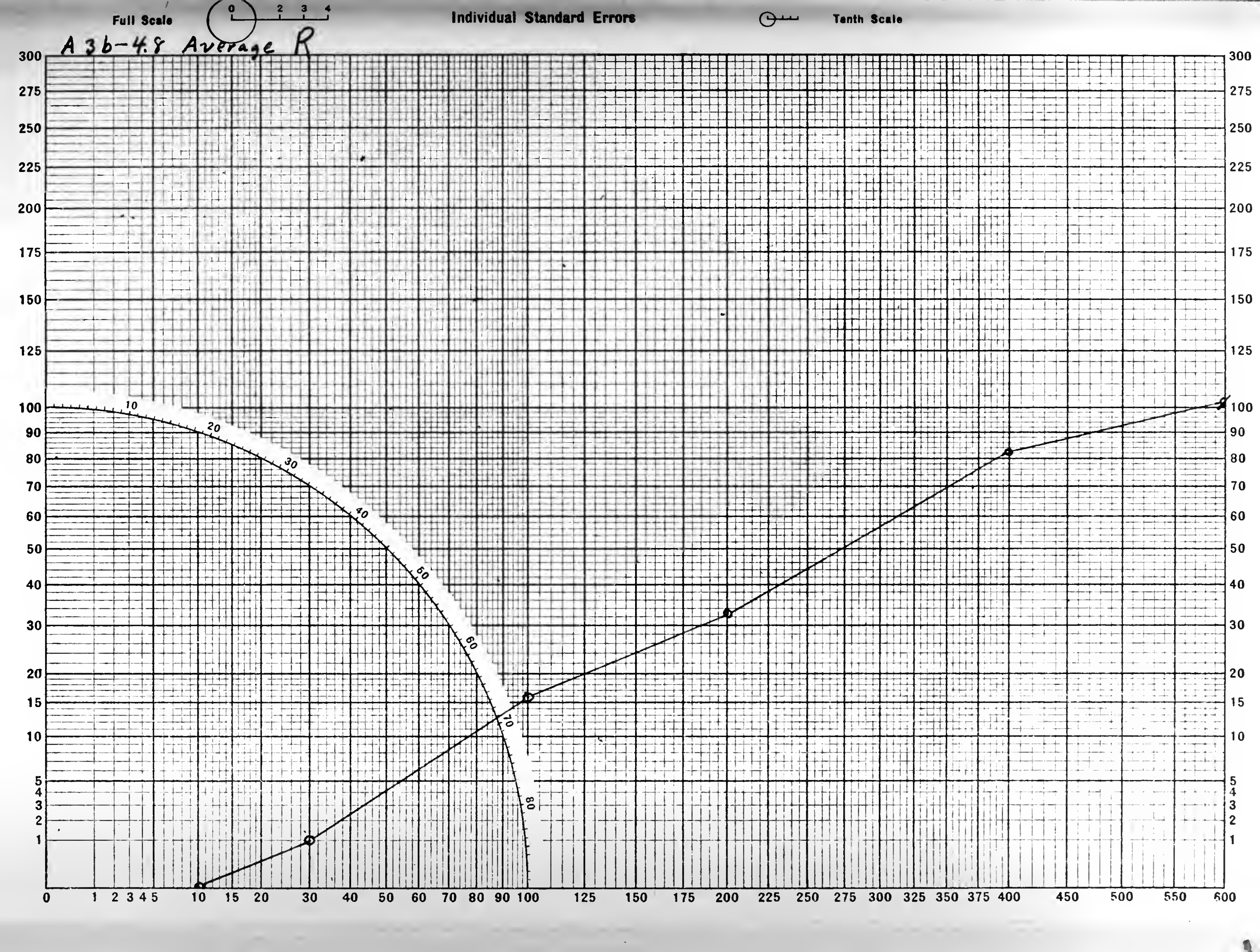
A2d-5.8 Average R



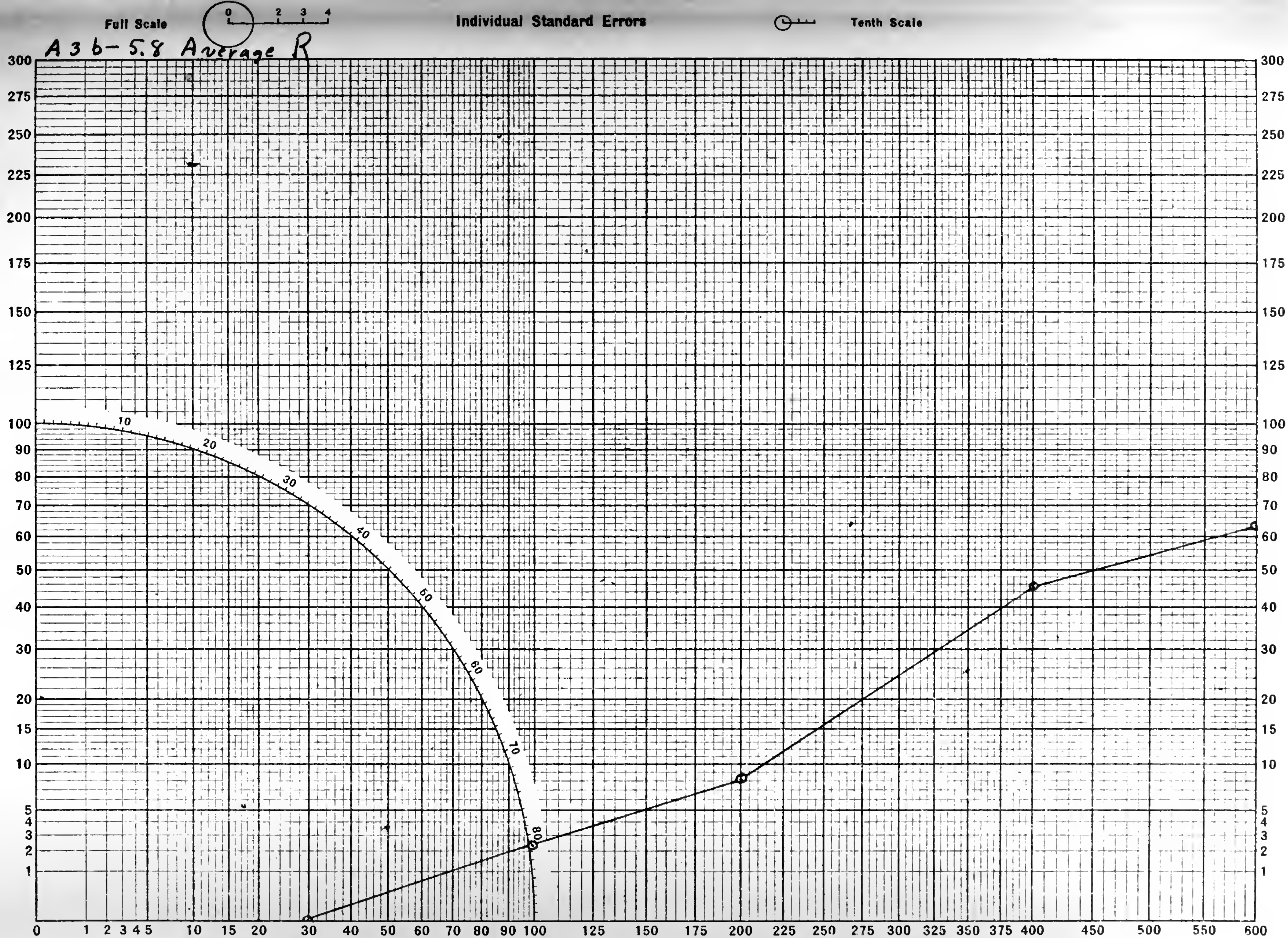

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 3a-4.8 Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80

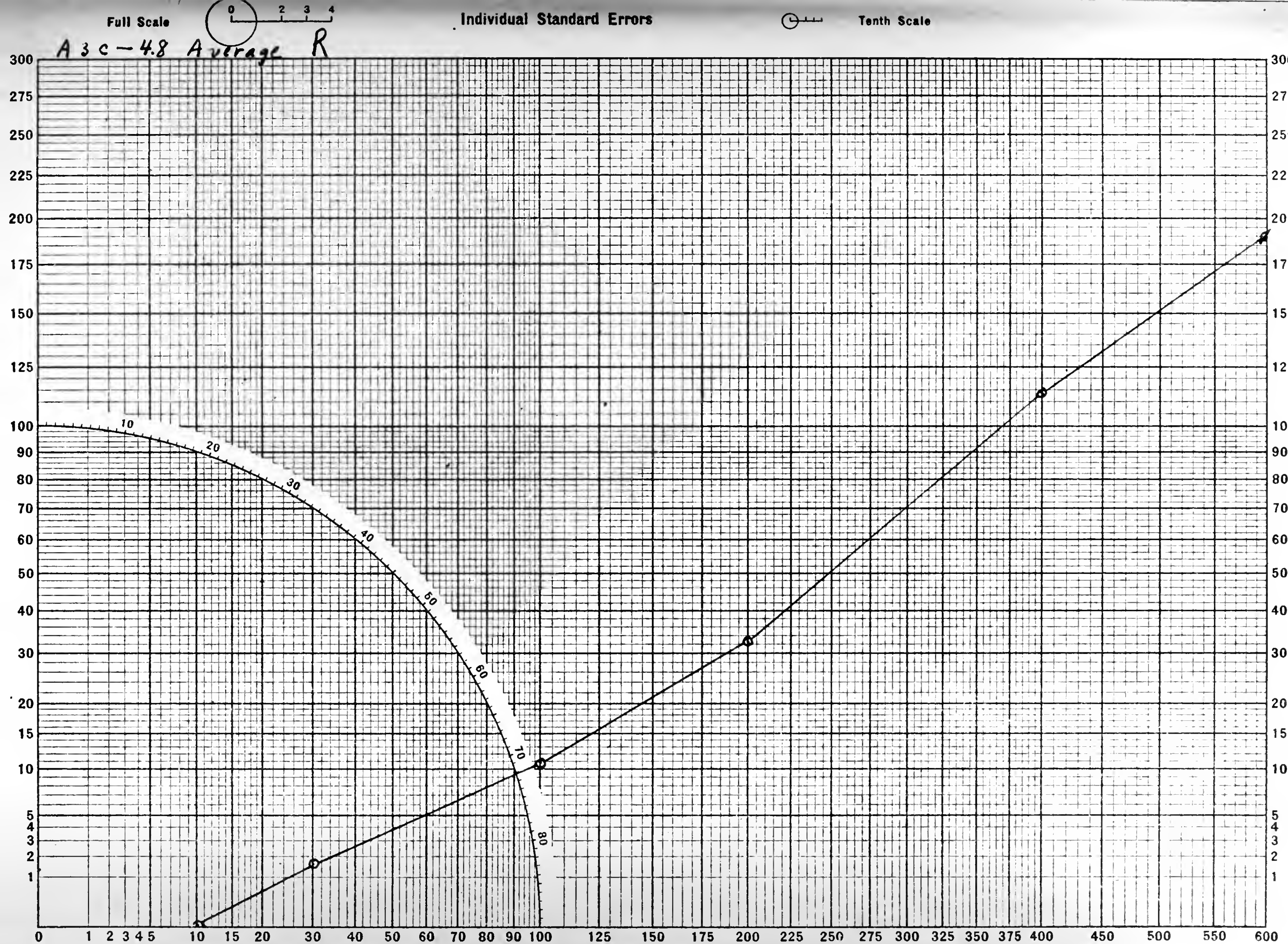


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 3a-5.8 Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

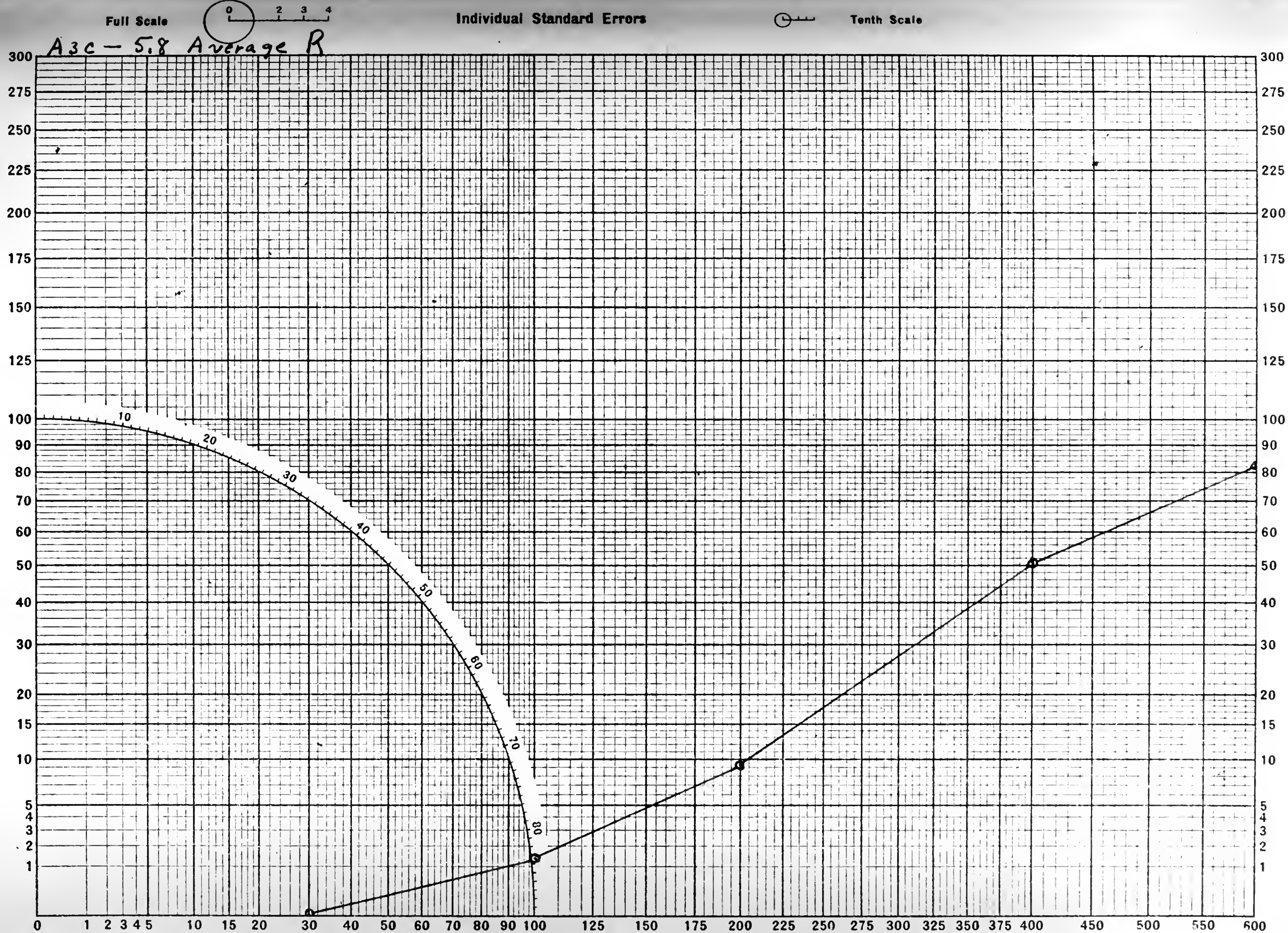

Full Scale
Individual Standard Errors
Tenth Scale
A 3b-4.8 Average R

A 3 b - 5.8 Average R



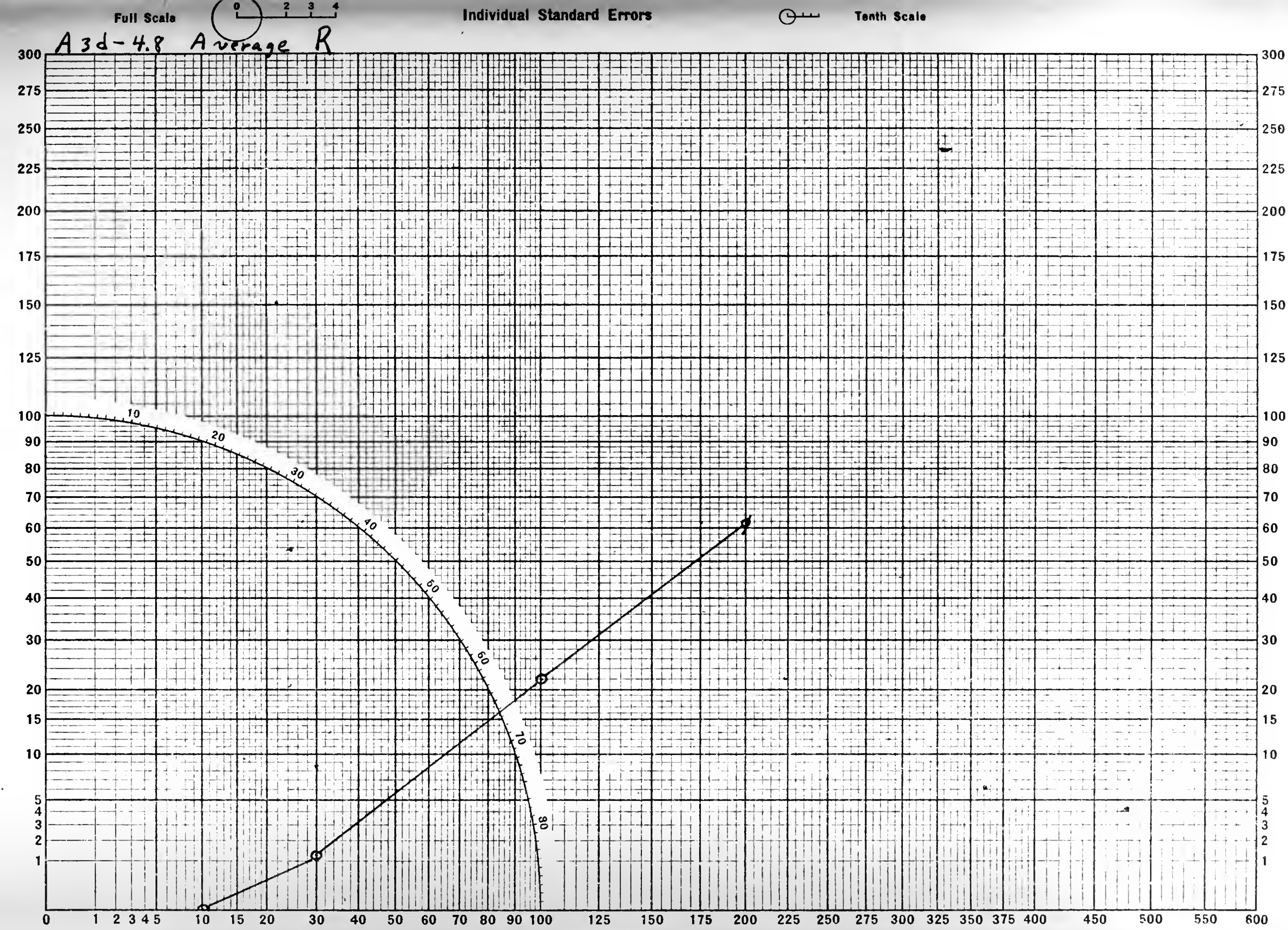


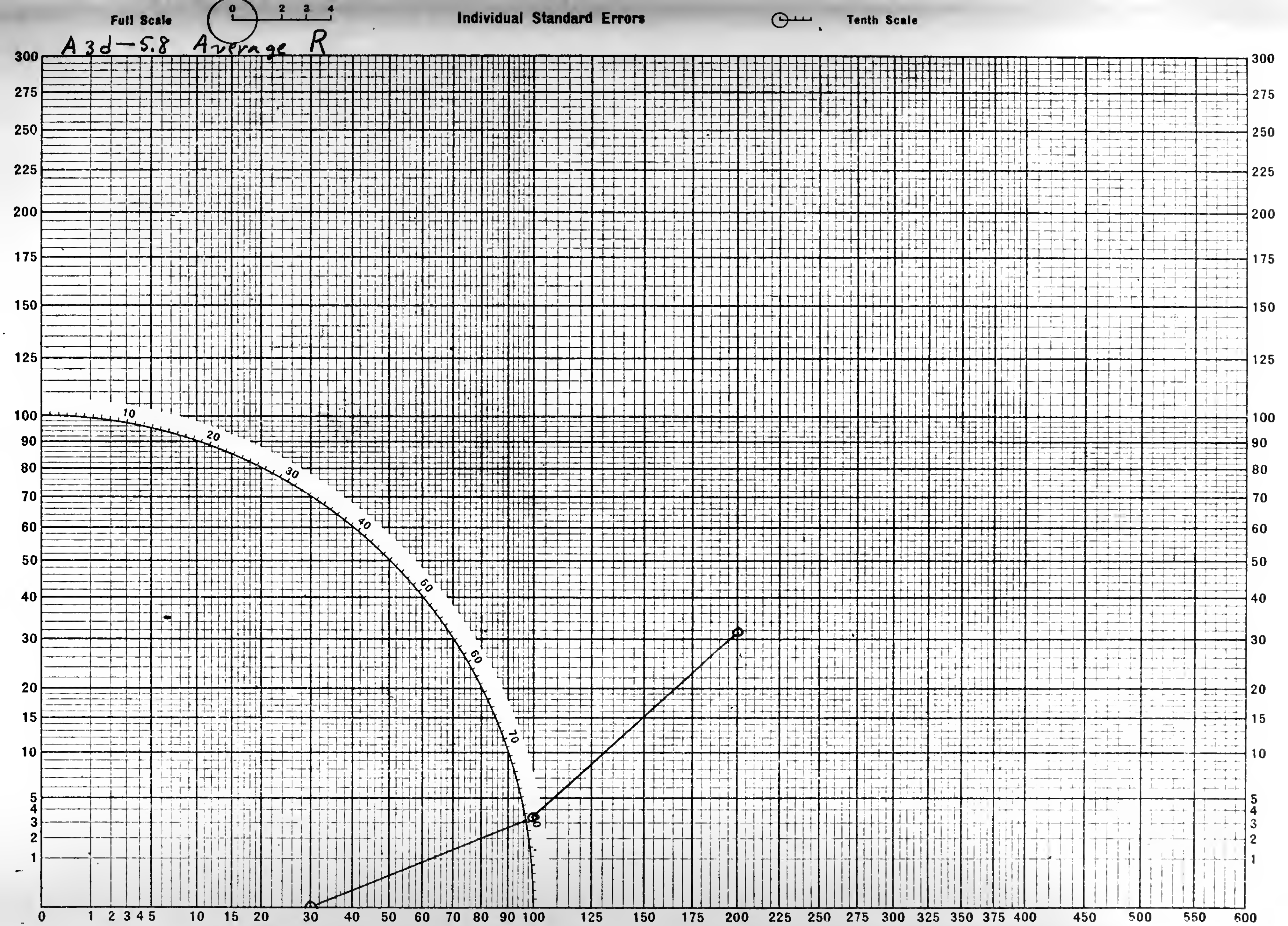
Full Scale
Individual Standard Errors
Tenth Scale
A 3 c — 4.8 Average R



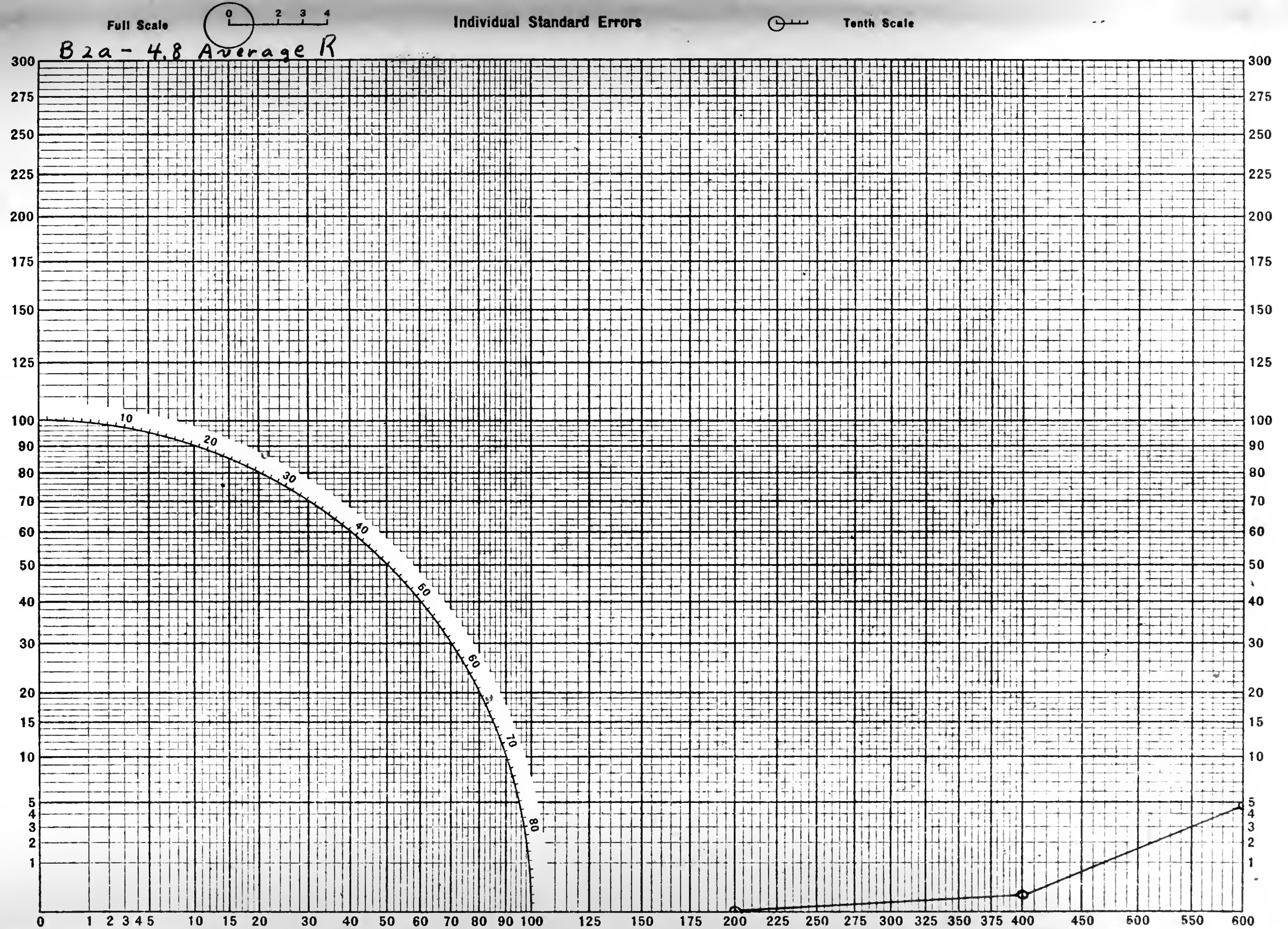
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A3c — 5.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

A3d-4.8 Average R



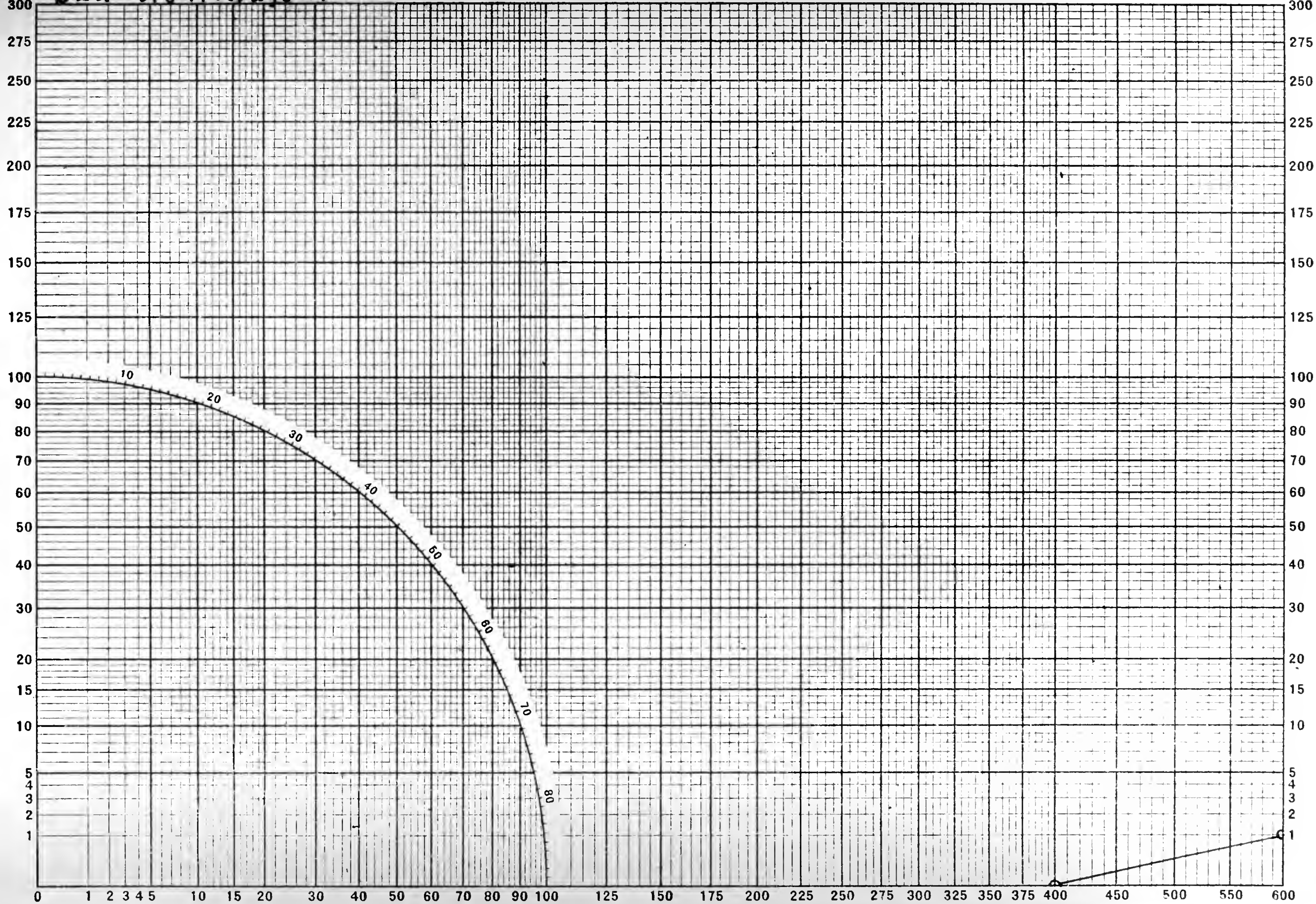

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A3d—5.8 Average R
10 20 30 40 50 60 70
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1

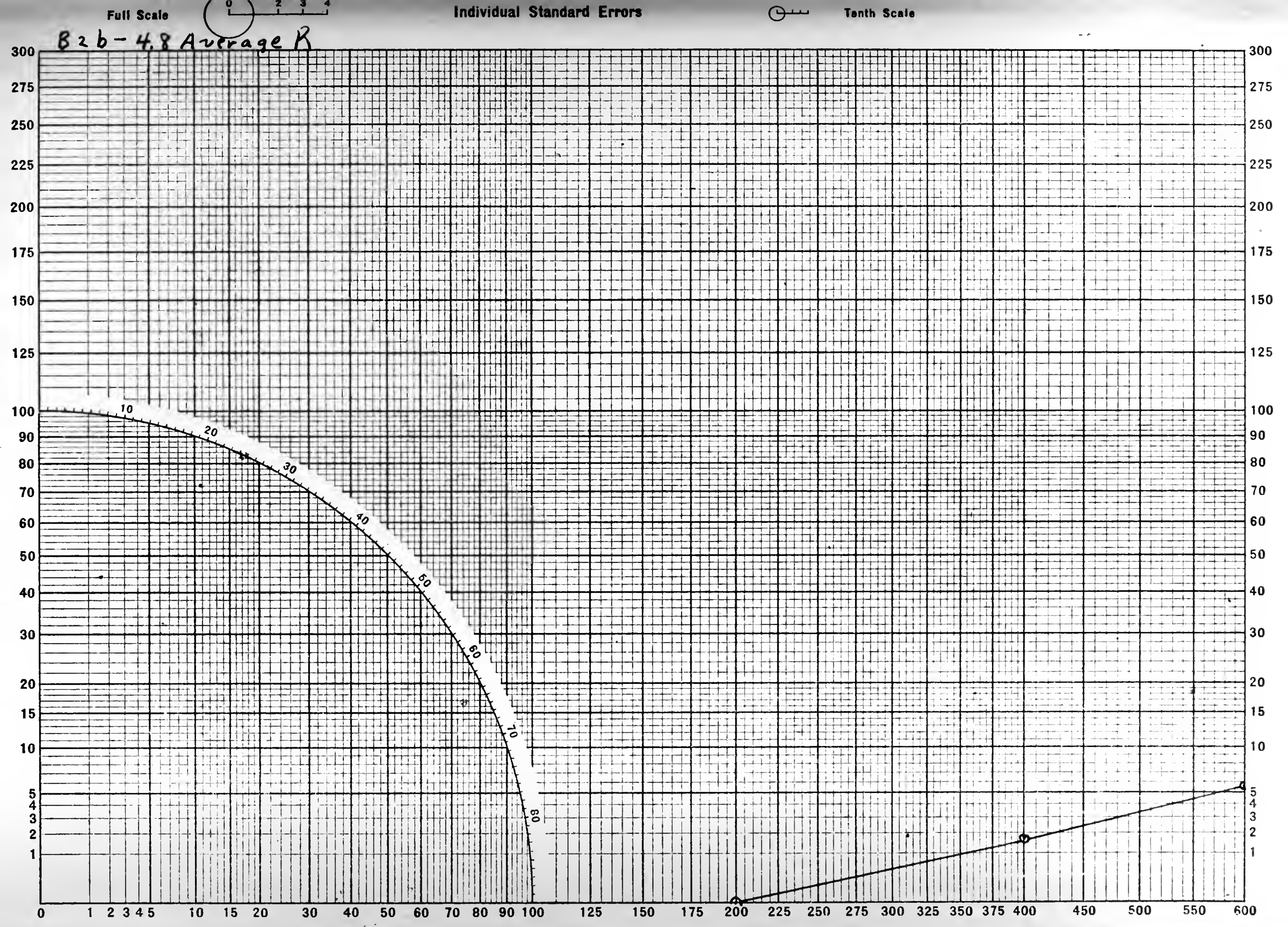
B 2a - 4.8 Average R



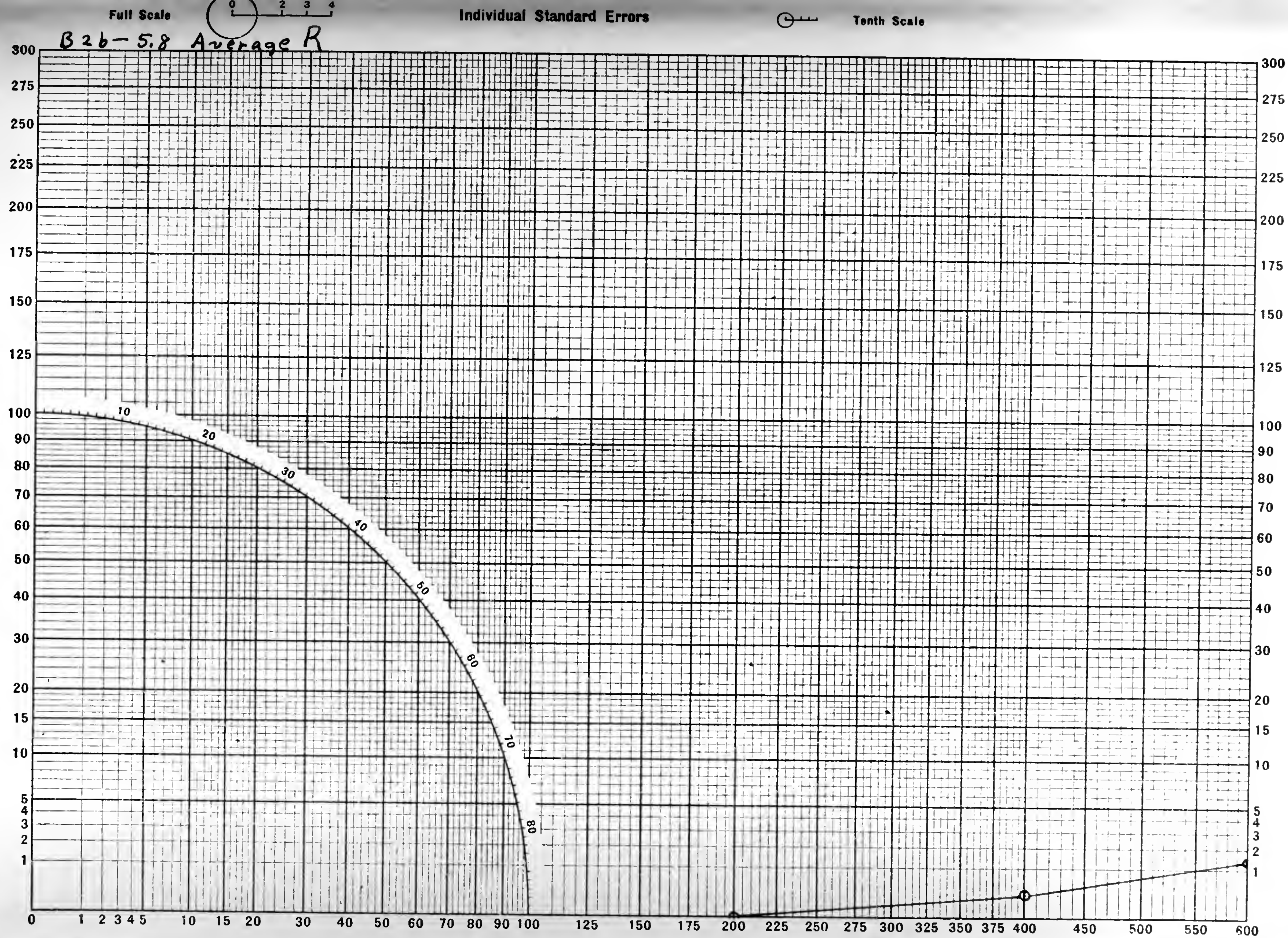
Full Scale Individual Standard Errors Tanth Scale

B2a-5.8 Average R

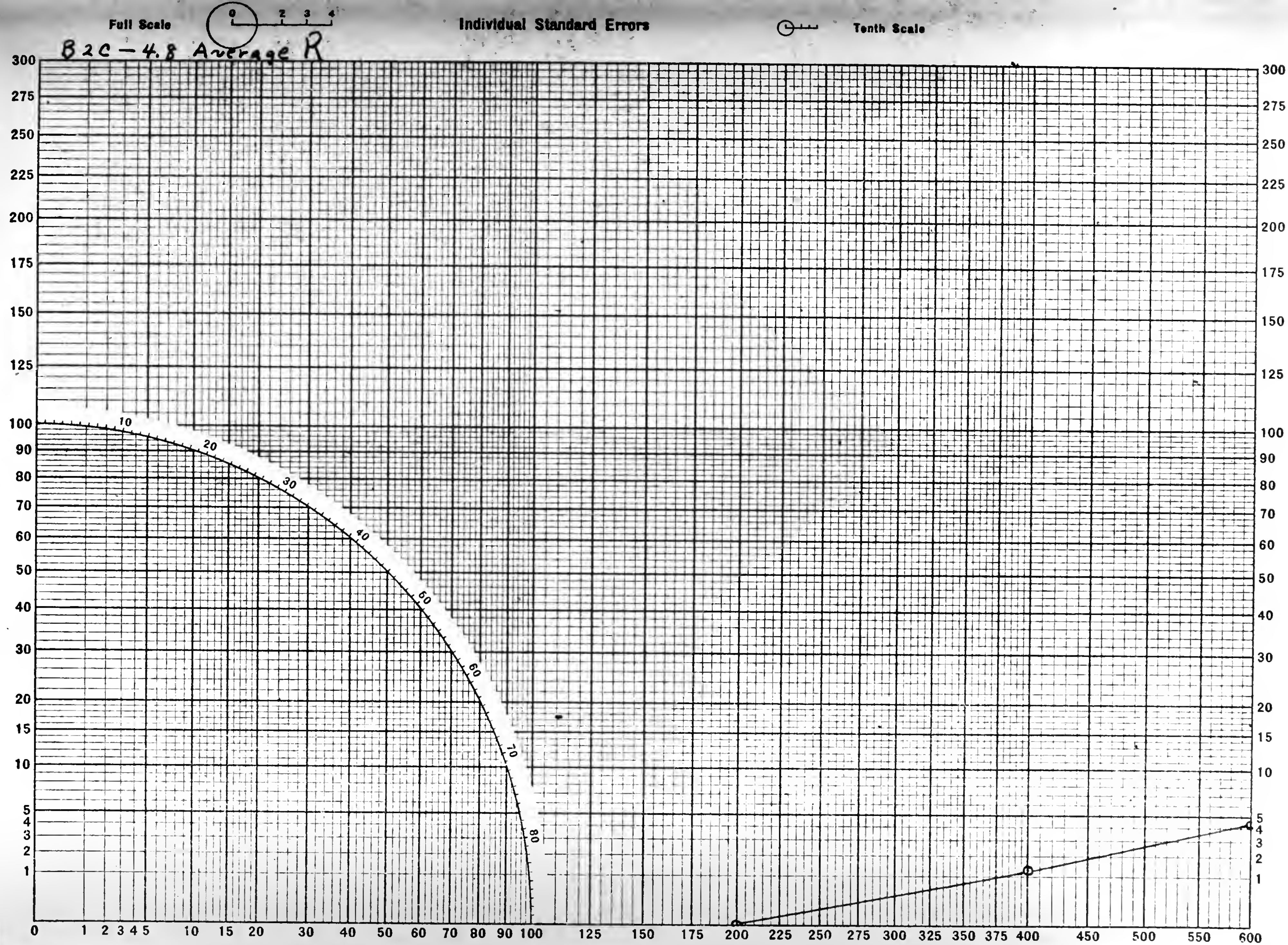




Full Scale
Individual Standard Errors
Tenth Scale
B 2 b - 4.8 Average R

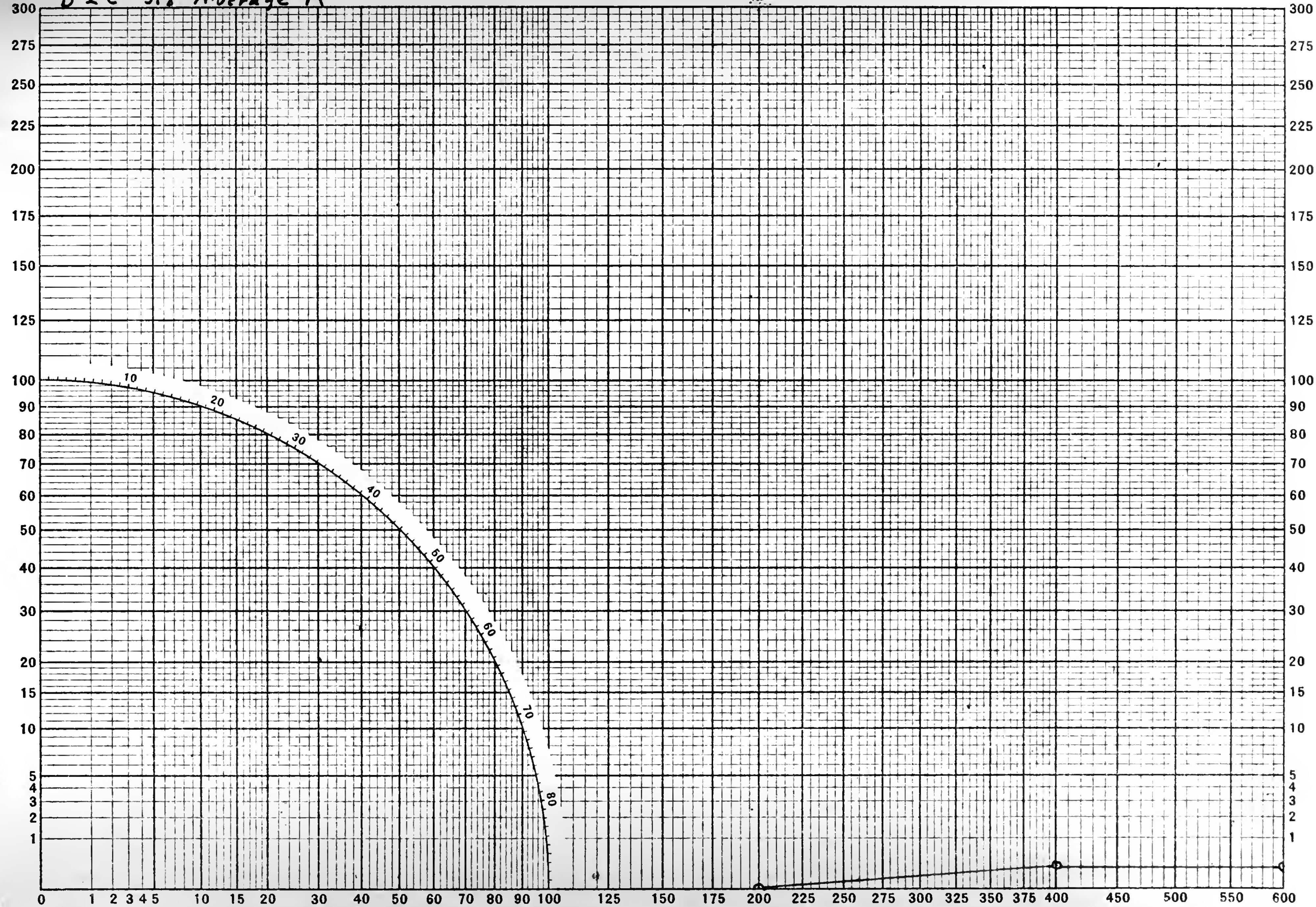


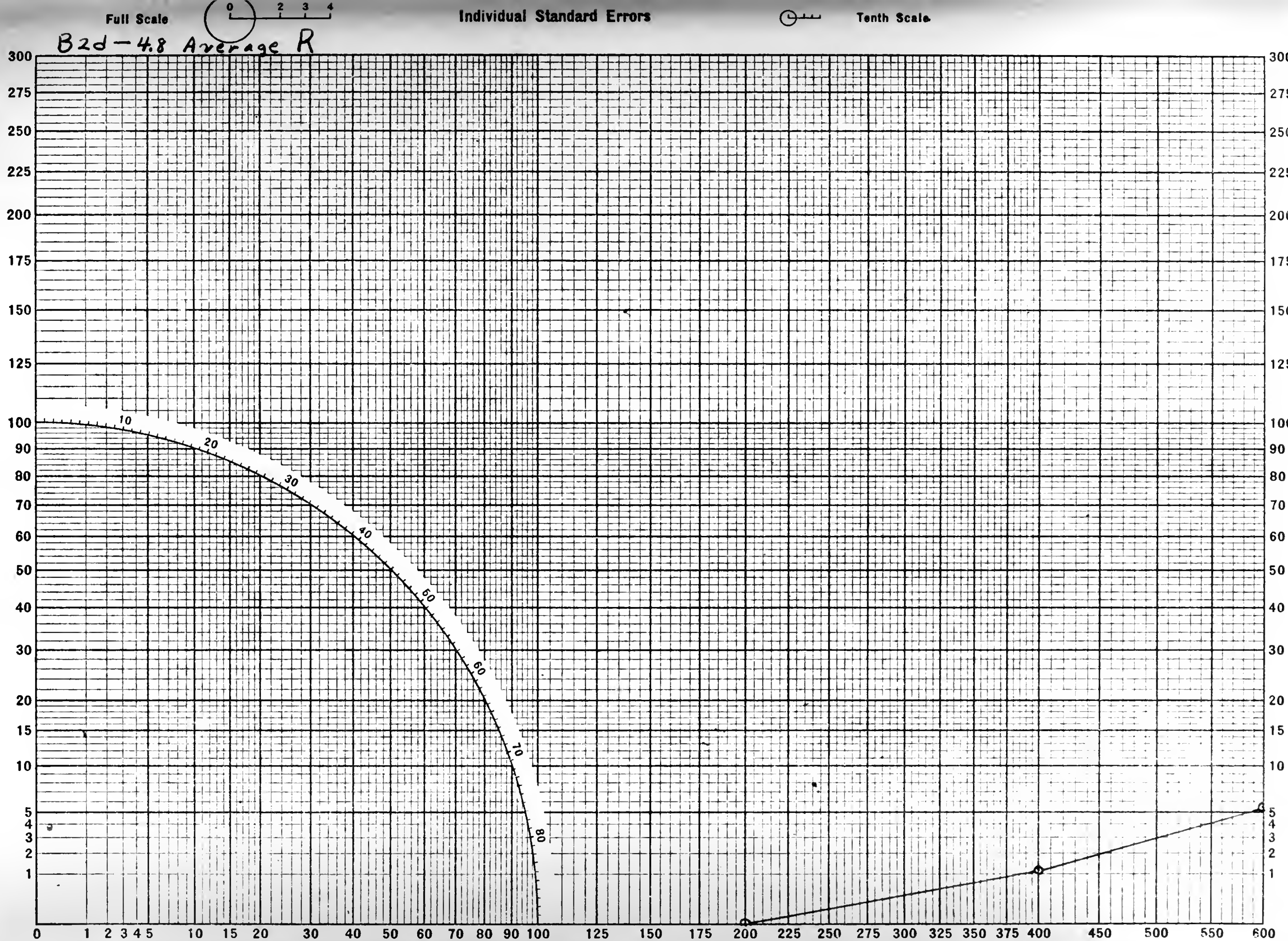
Full Scale
Individual Standard Errors
Tenth Scale
B 2b-5.8 Average R


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B2C — 4.8 Average R

Full Scale 0 2 3 4 **Individual Standard Errors** Tenth Scale

B 2 C-5.8 Average R



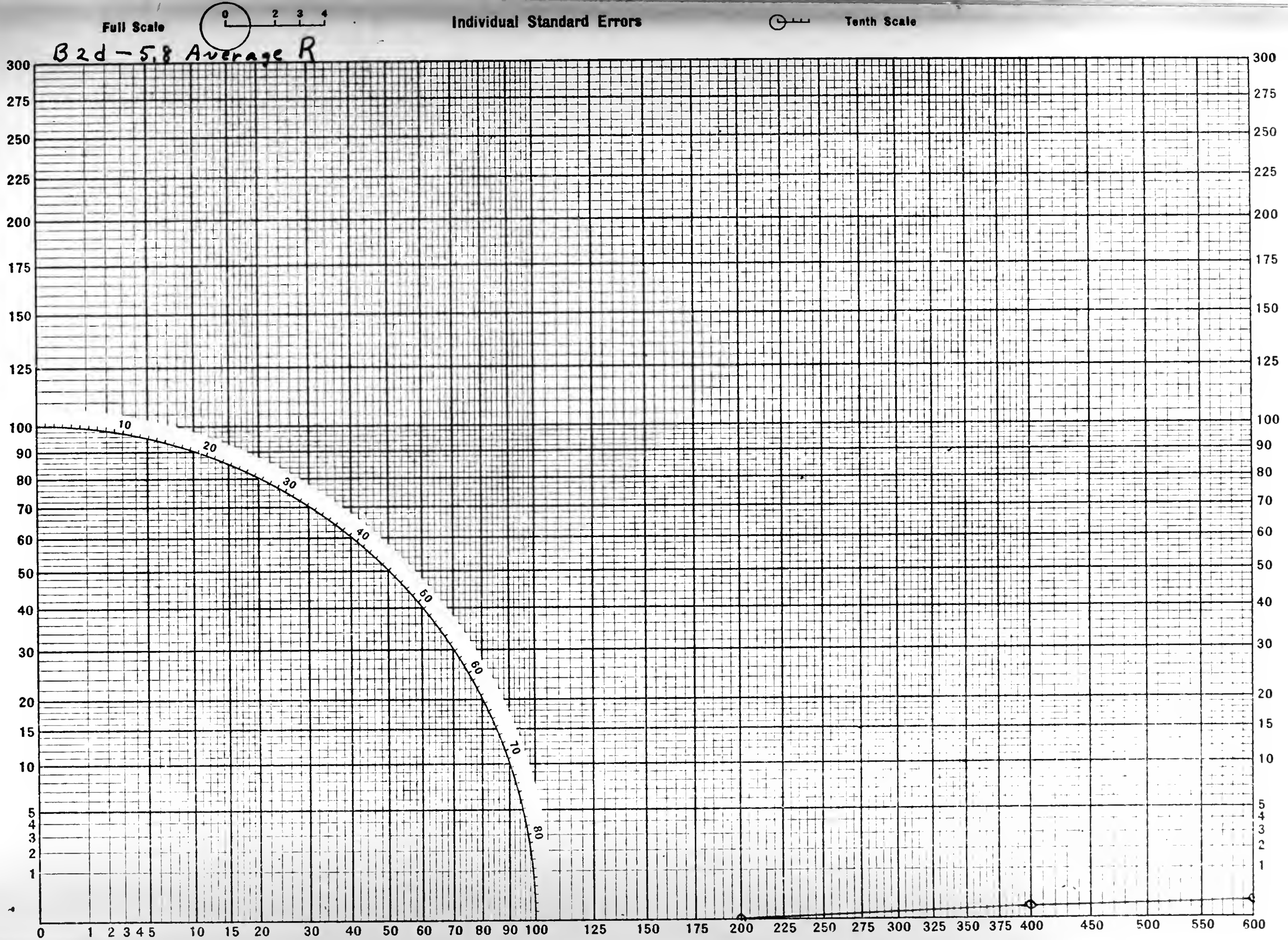

Full Scale
Individual Standard Errors
Tenth Scale
B2d — 4.8 Average R
0 2 3 4
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

Full Scale

Individual Standard Errors

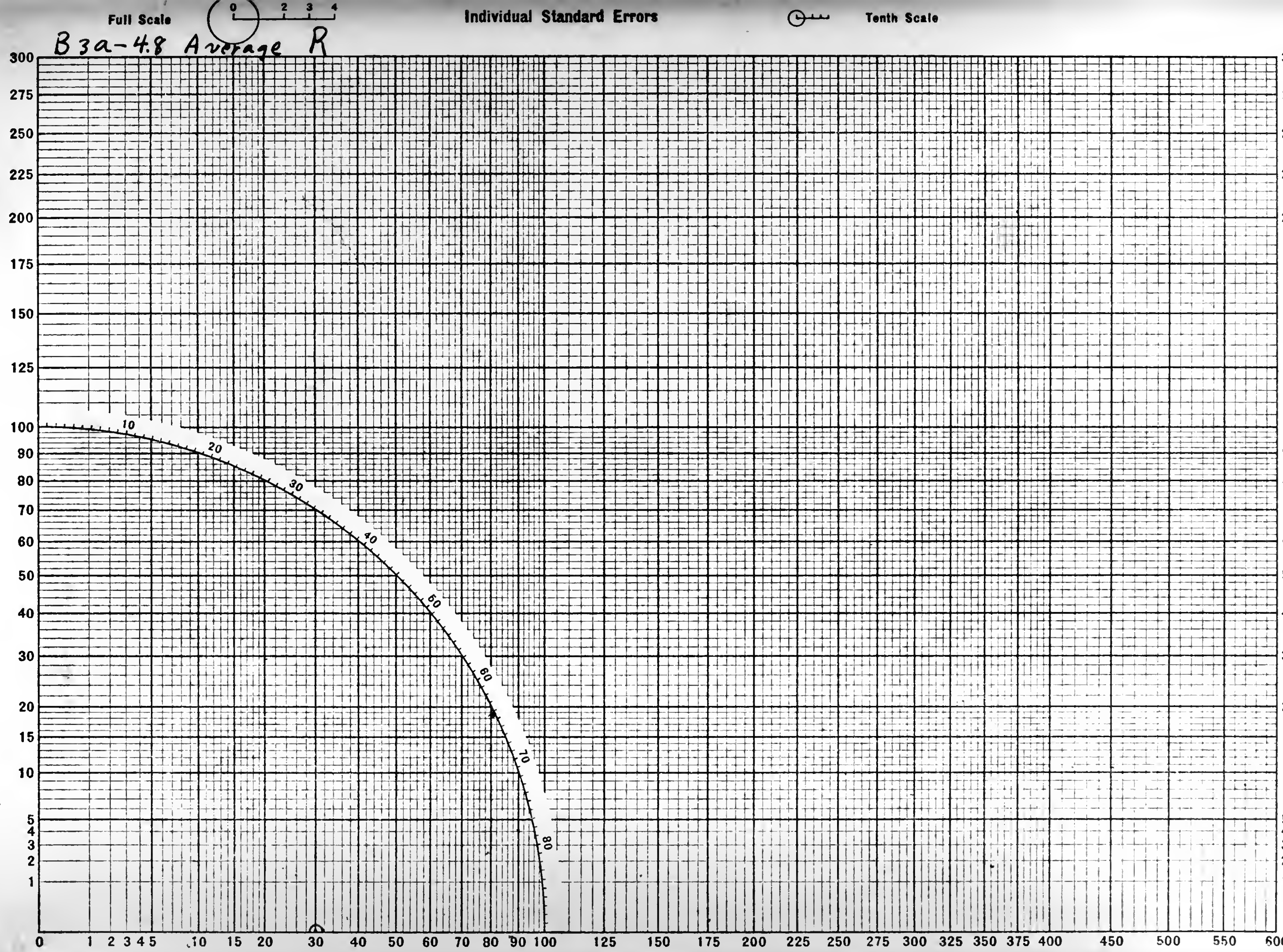
Tenth Scale

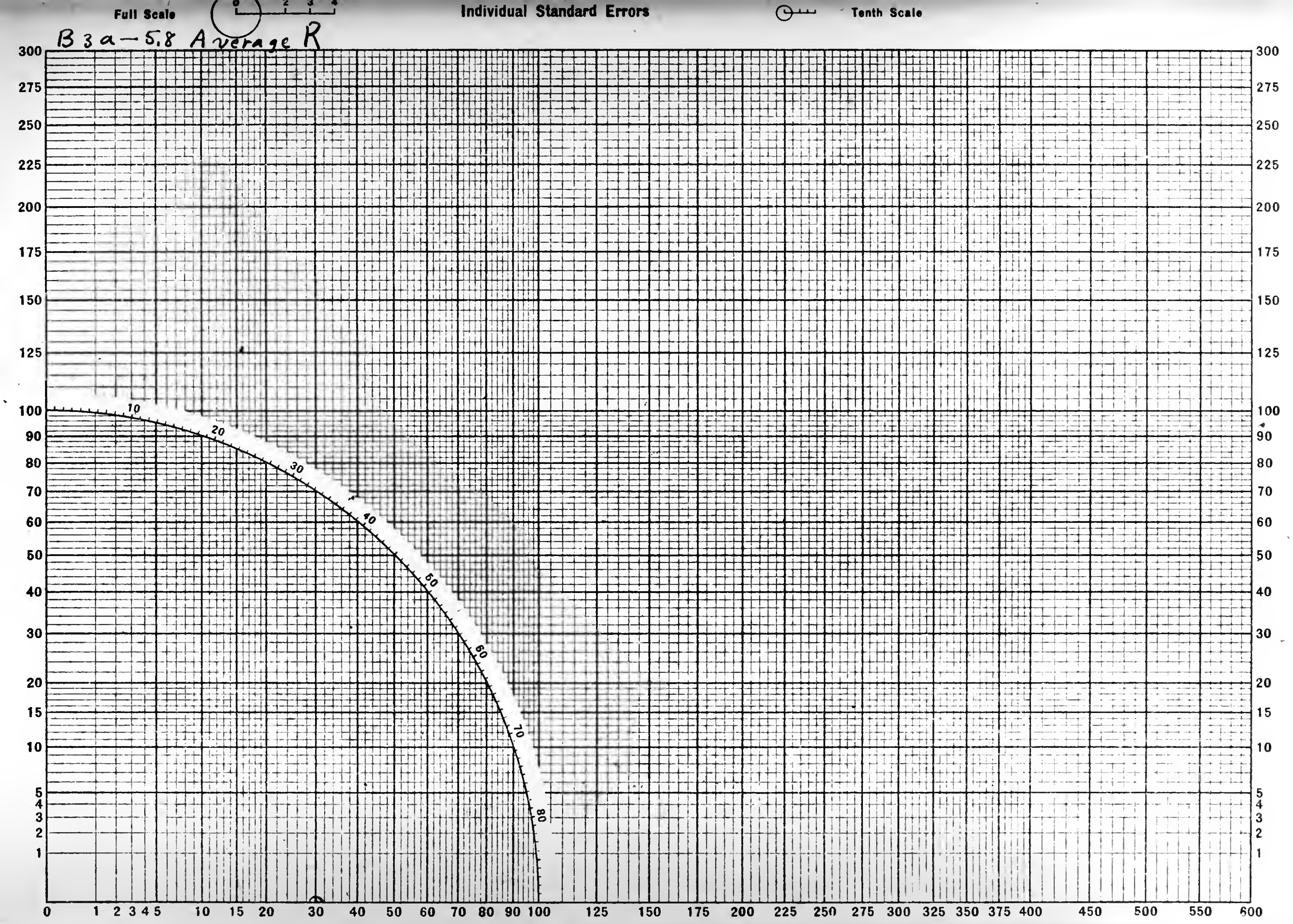
B2d – 5.8 Average R



Full Scale | Individual Standard Errors | Tenth Scale

B 3a-4.8 Average R





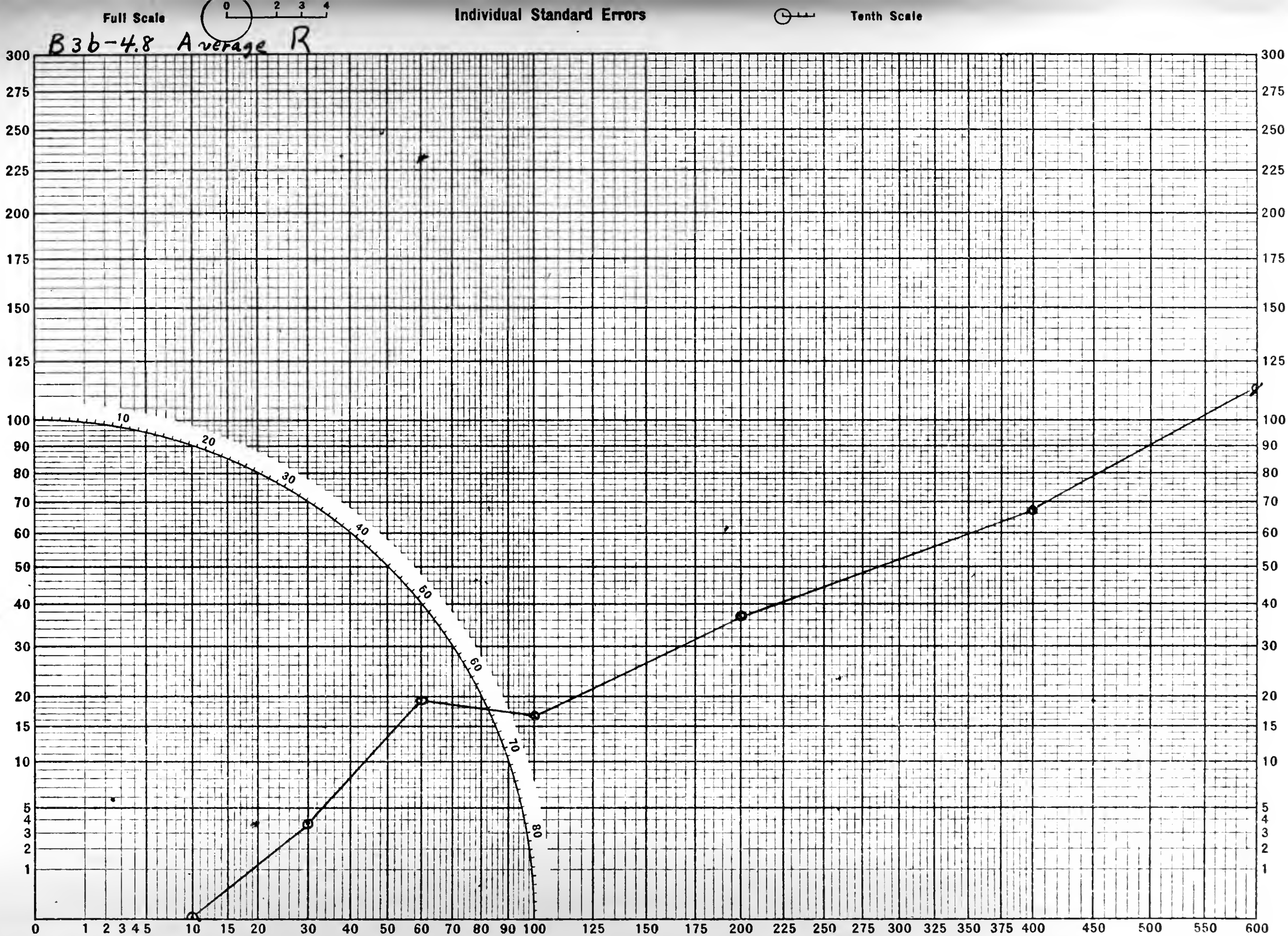
Full Scale
0 1 2 3 4
Individual Standard Errors
Tenth Scale
B 3 a — 5.8 Average R
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300
10 20 30 40 50 60 70 80

Full Scale

Individual Standard Errors

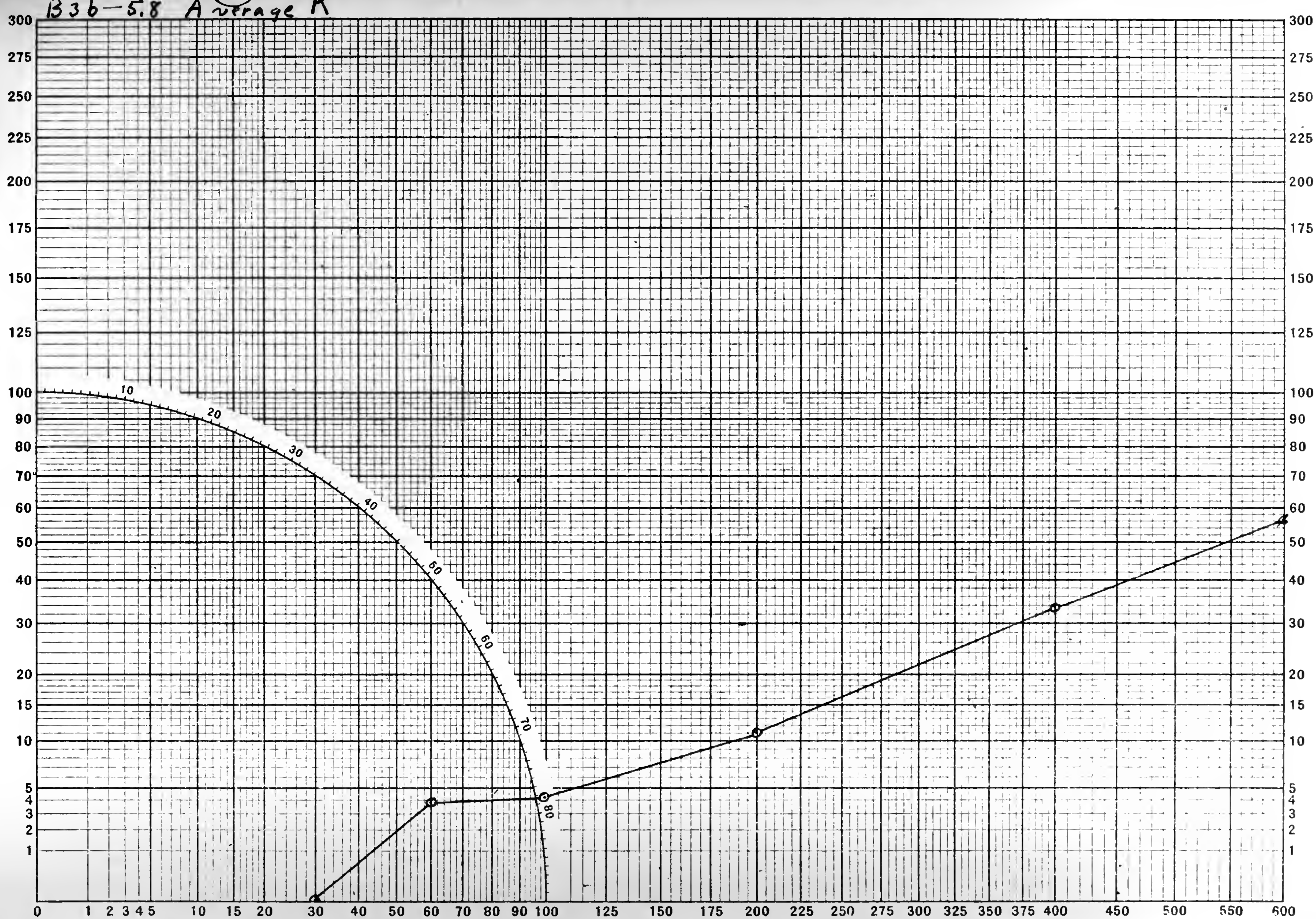
Tenth Scale

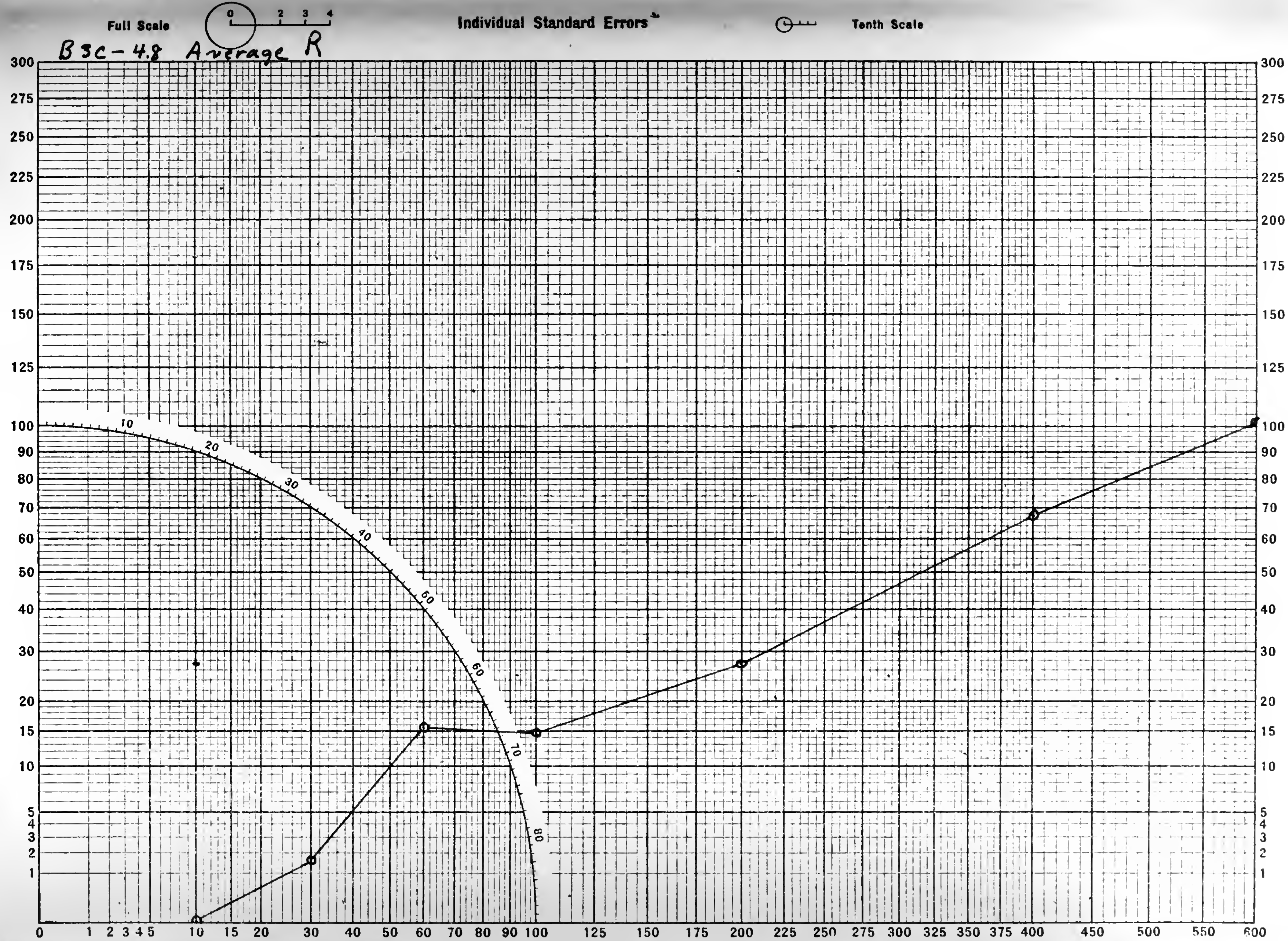
B3b-4.8 Average R



Full Scale Individual Standard Errors Tenth Scale

B3b—5.8 Average R

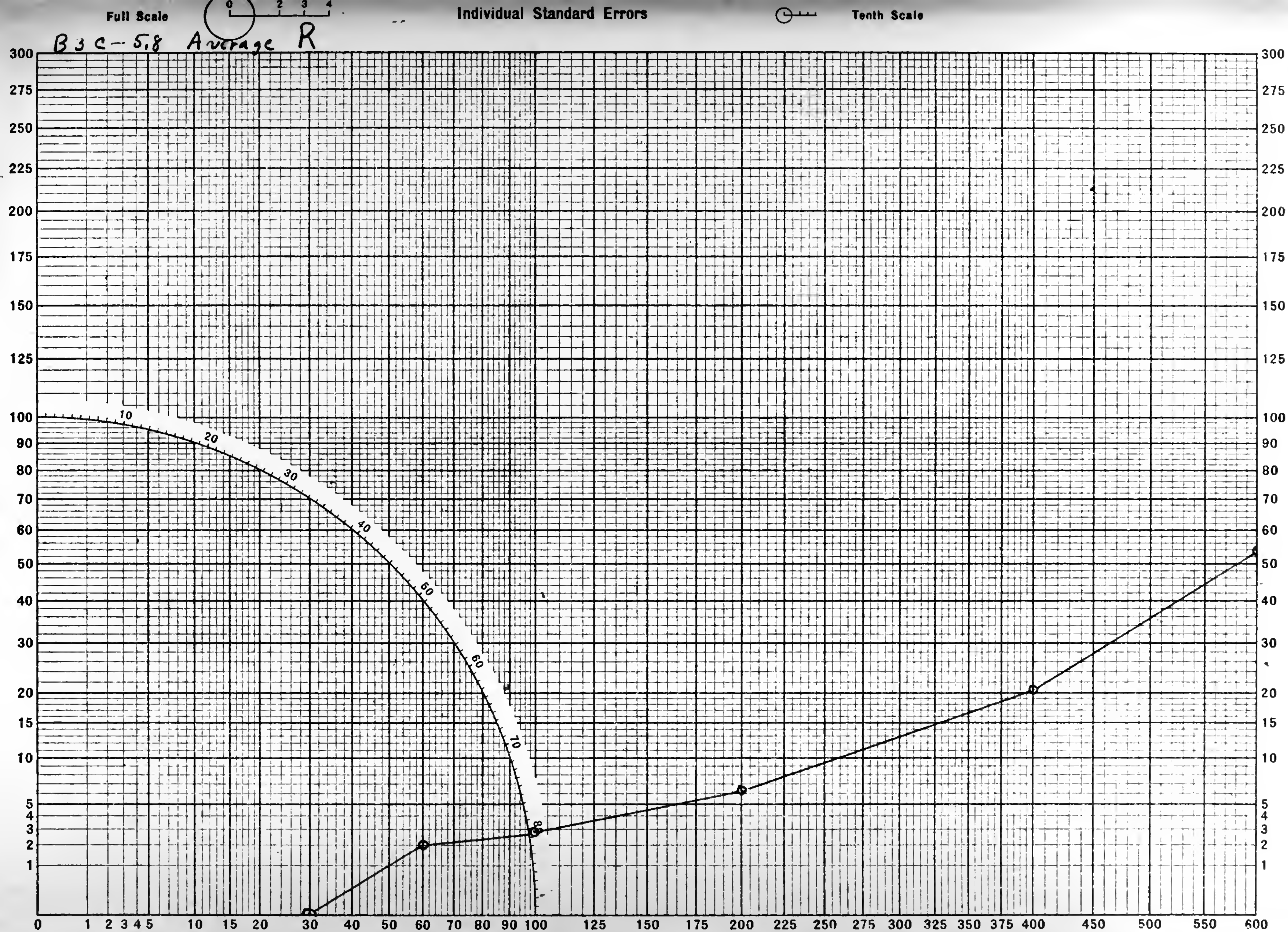




Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B3c-4.8 Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80

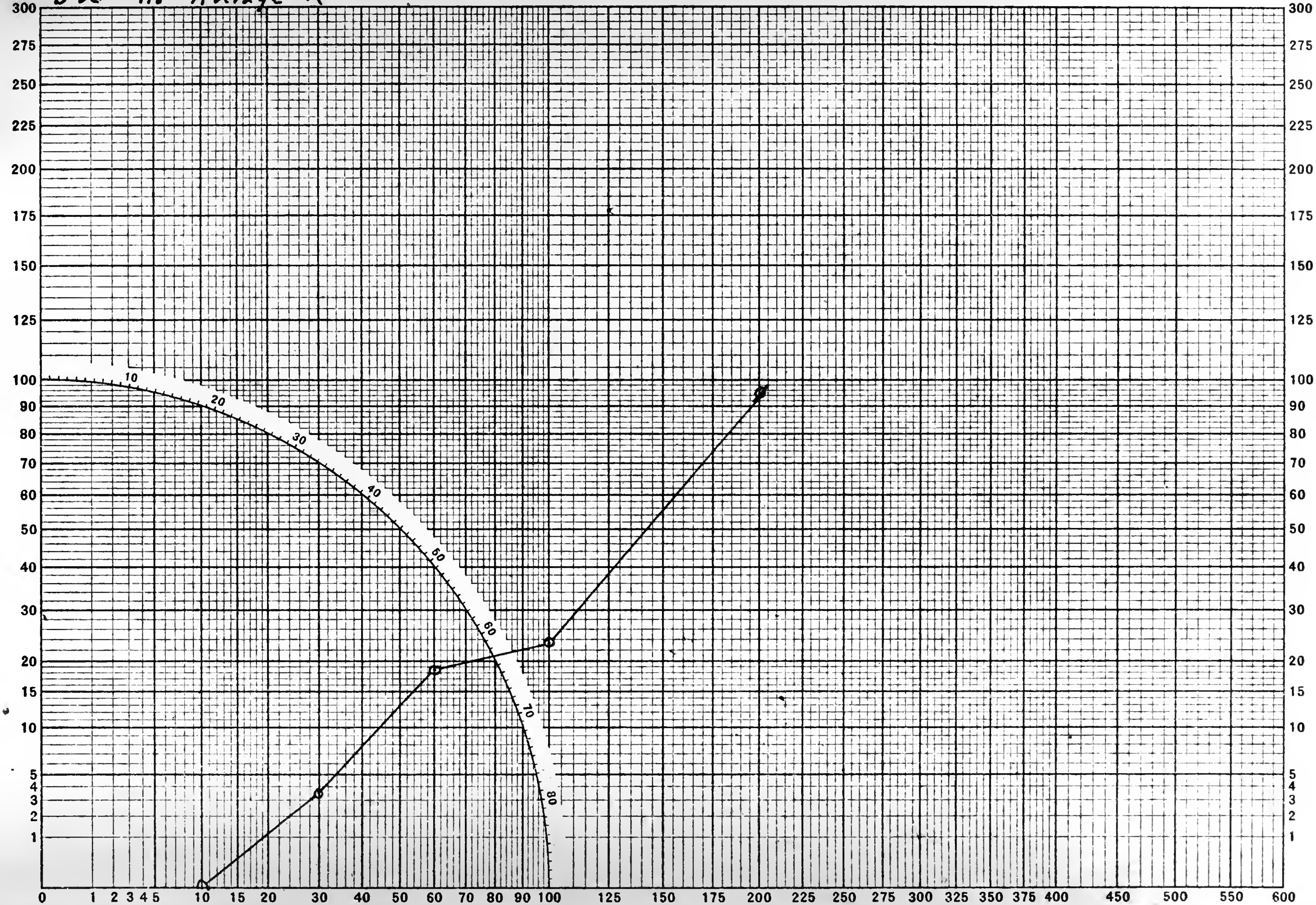
Full Scale Individual Standard Errors Tenth Scale

B3C-5.8 Average R



Full Scale   Individual Standard Errors   Tenth Scale

B 3d - 4.8 Average R

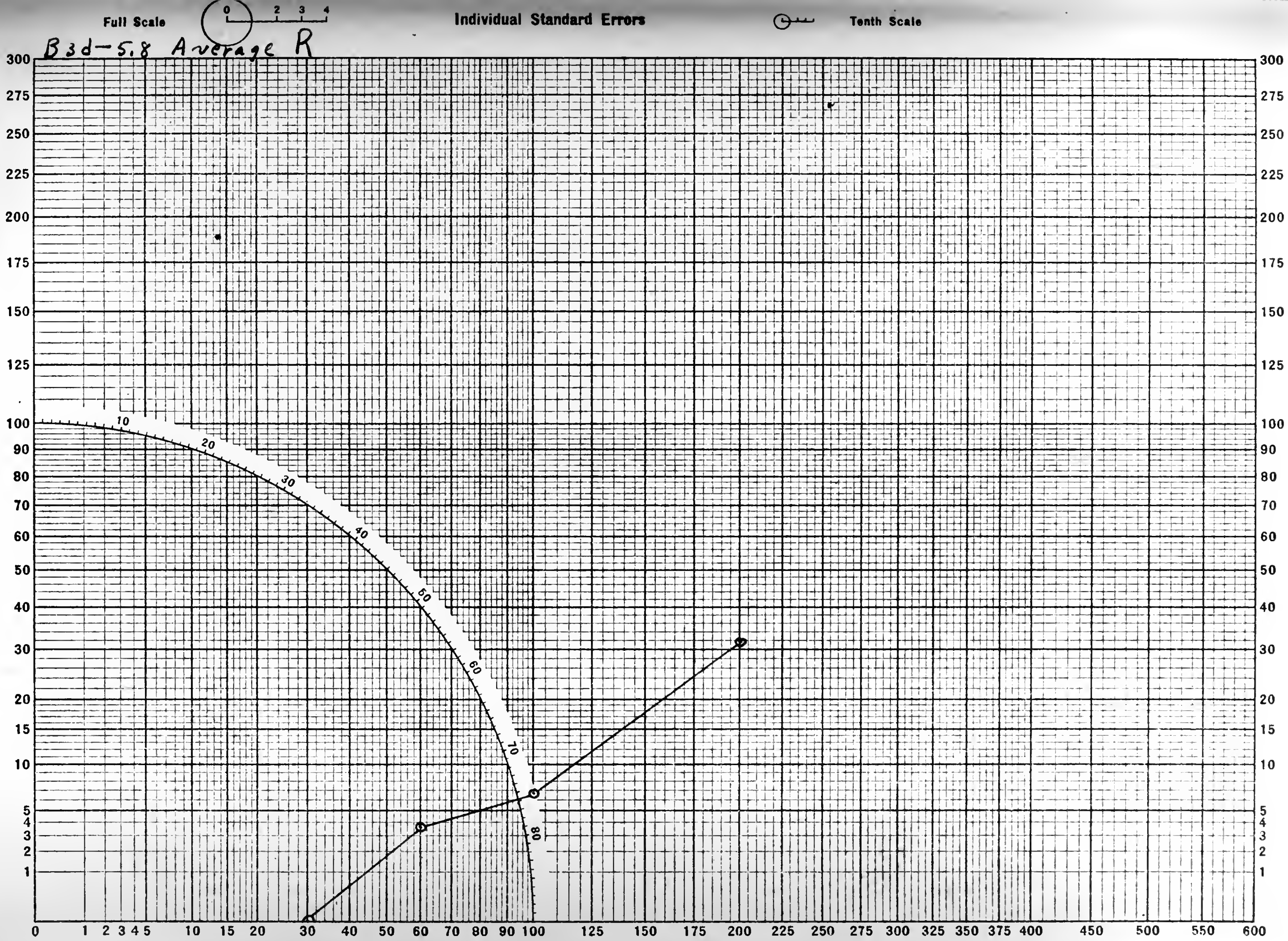


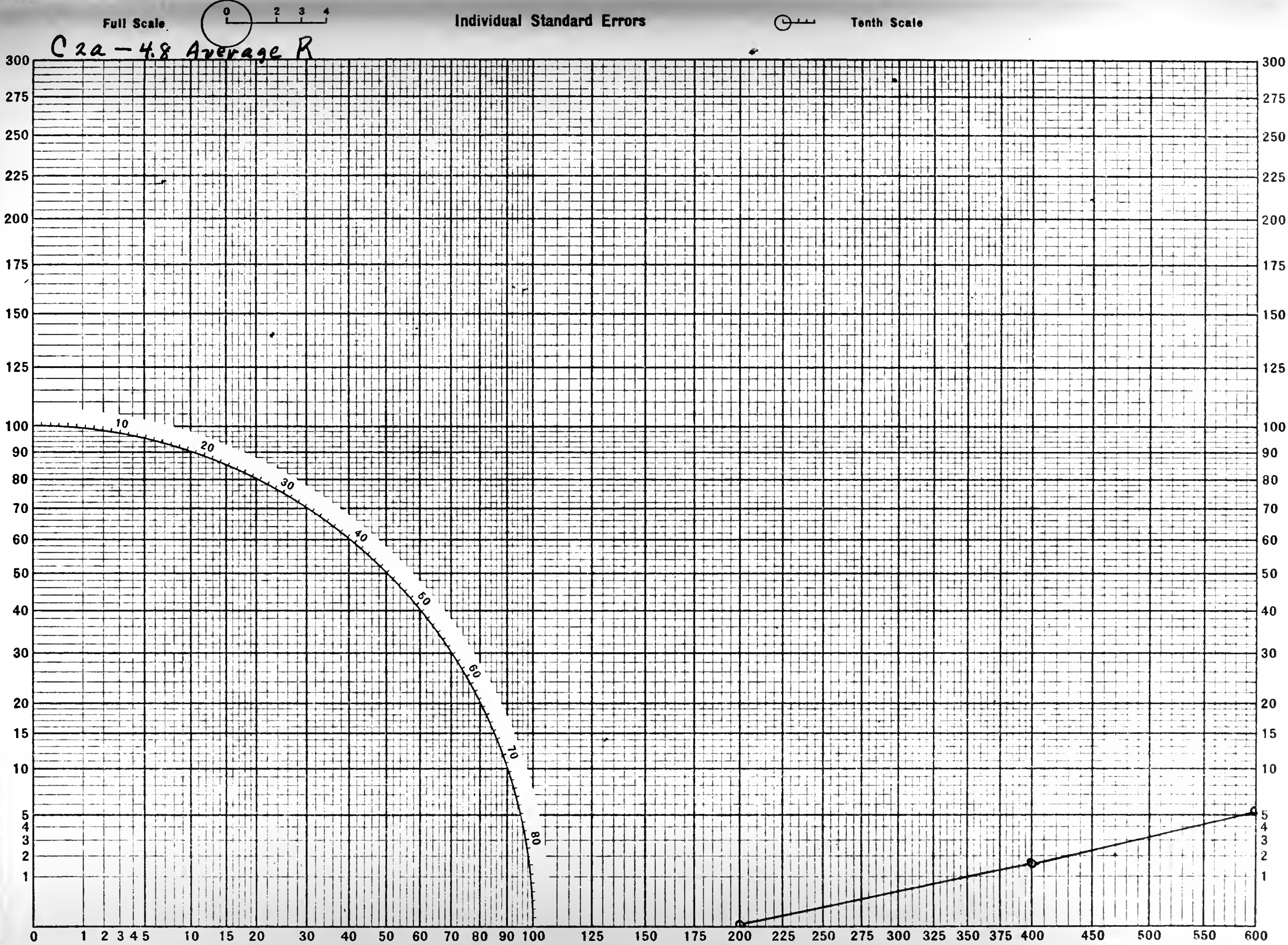
Full Scale

Individual Standard Errors

Tenth Scale

B3d-5.8 Average R




Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2a — 4.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80


Full Scale
0
2
3
4
Individual Standard Errors
Tenth Scale
C 2a — 5.8 Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10
15
20
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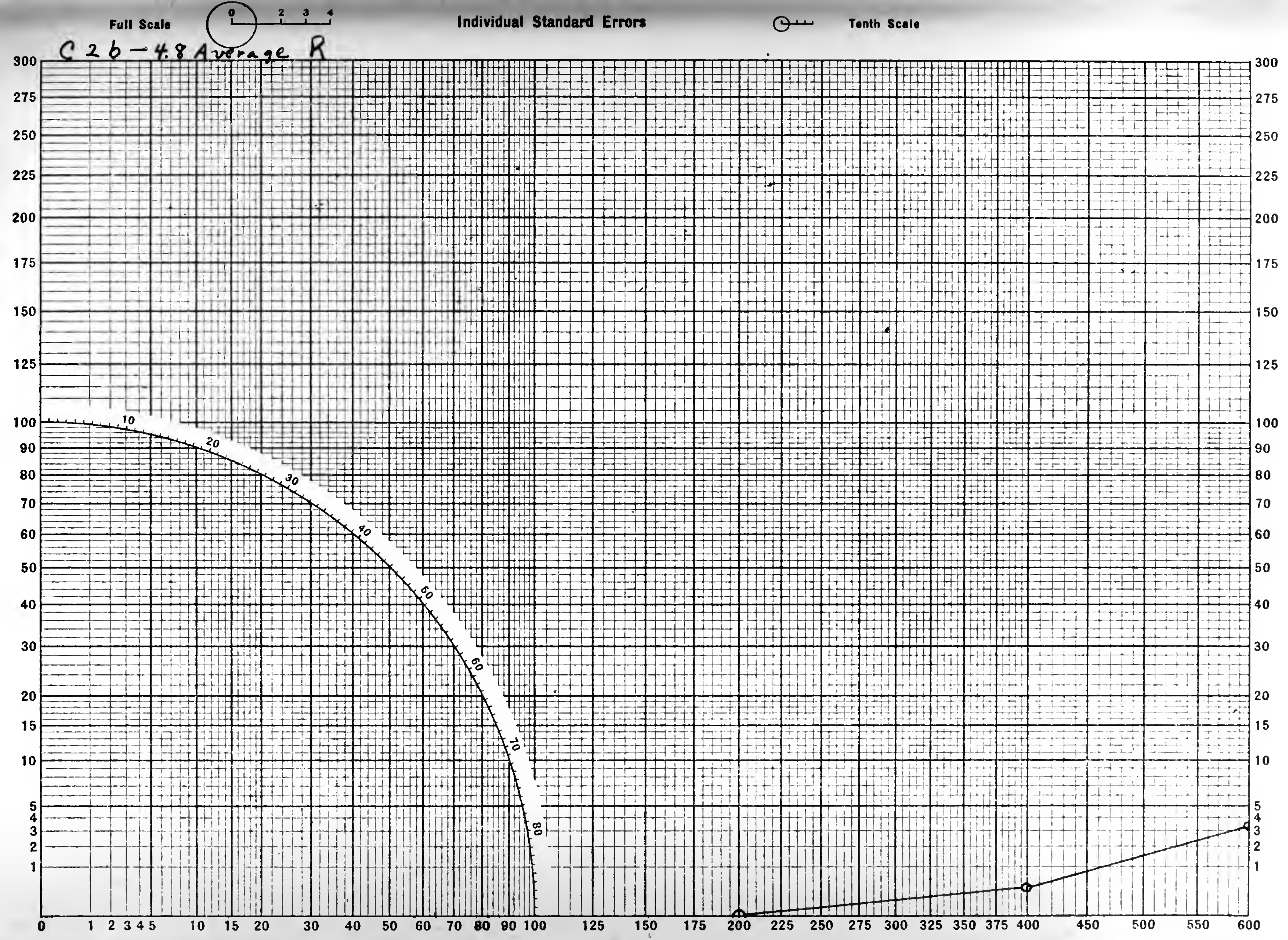
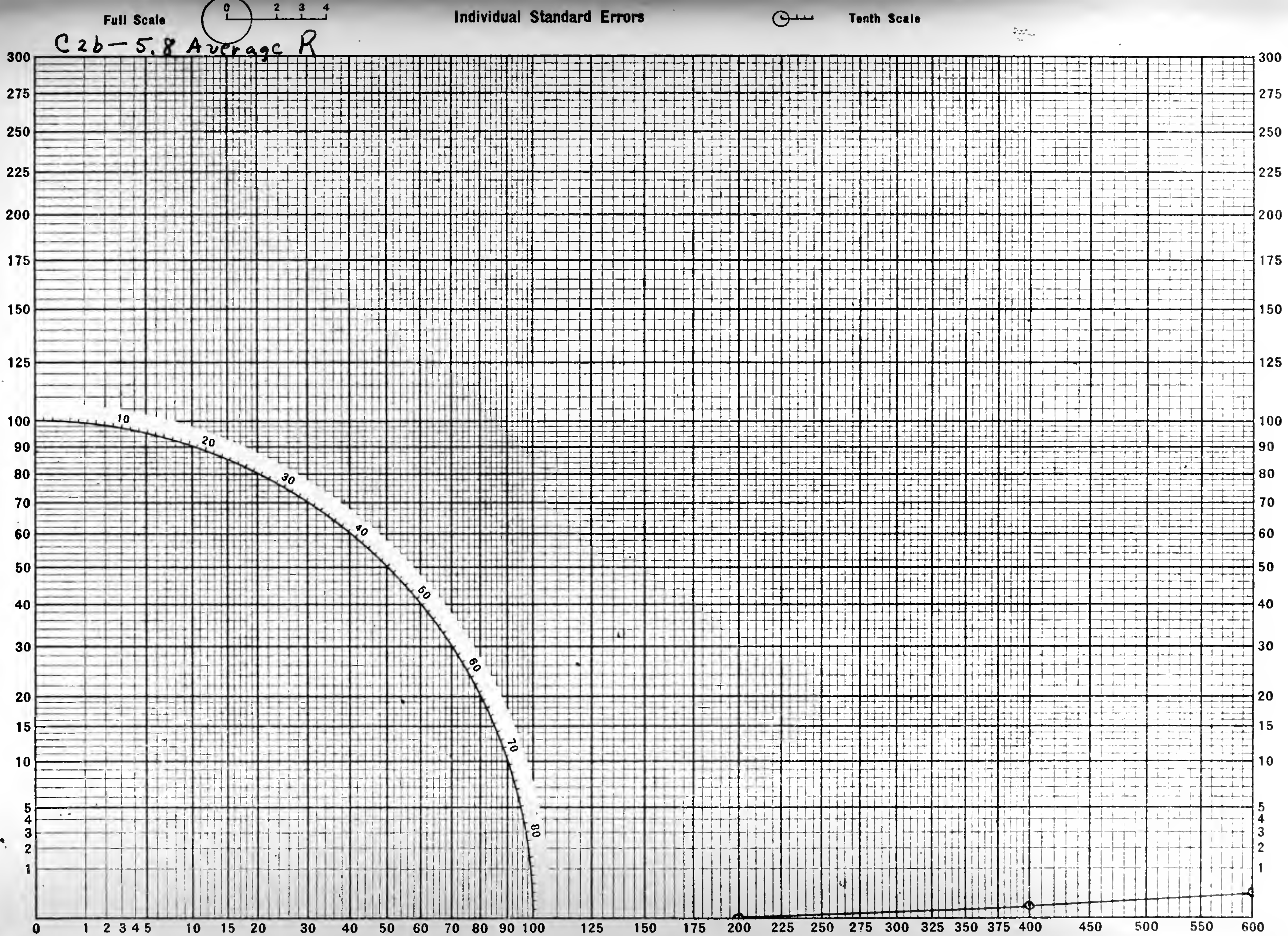

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2 b — 4.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

Full Scale

Individual Standard Errors

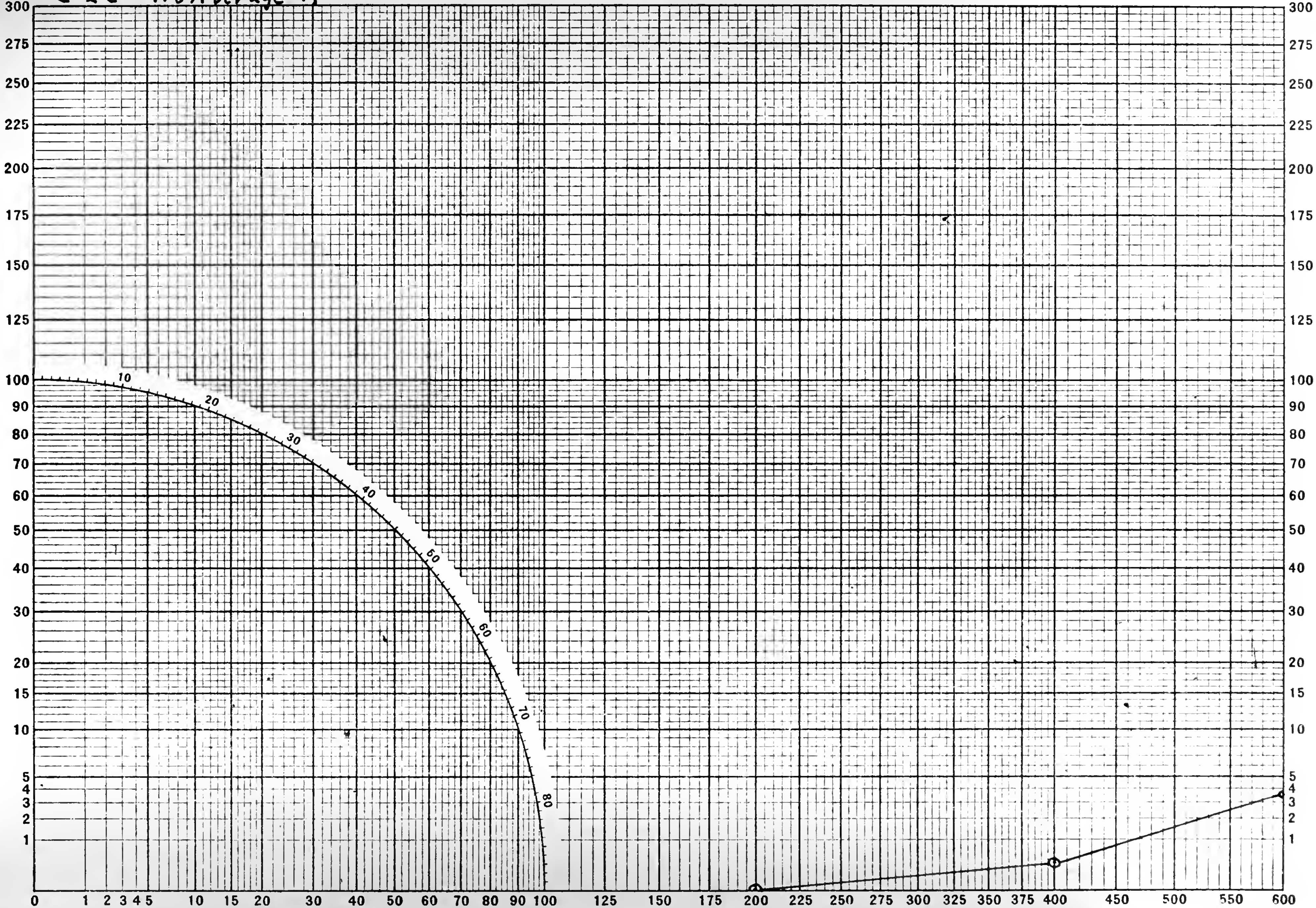
Tenth Scale

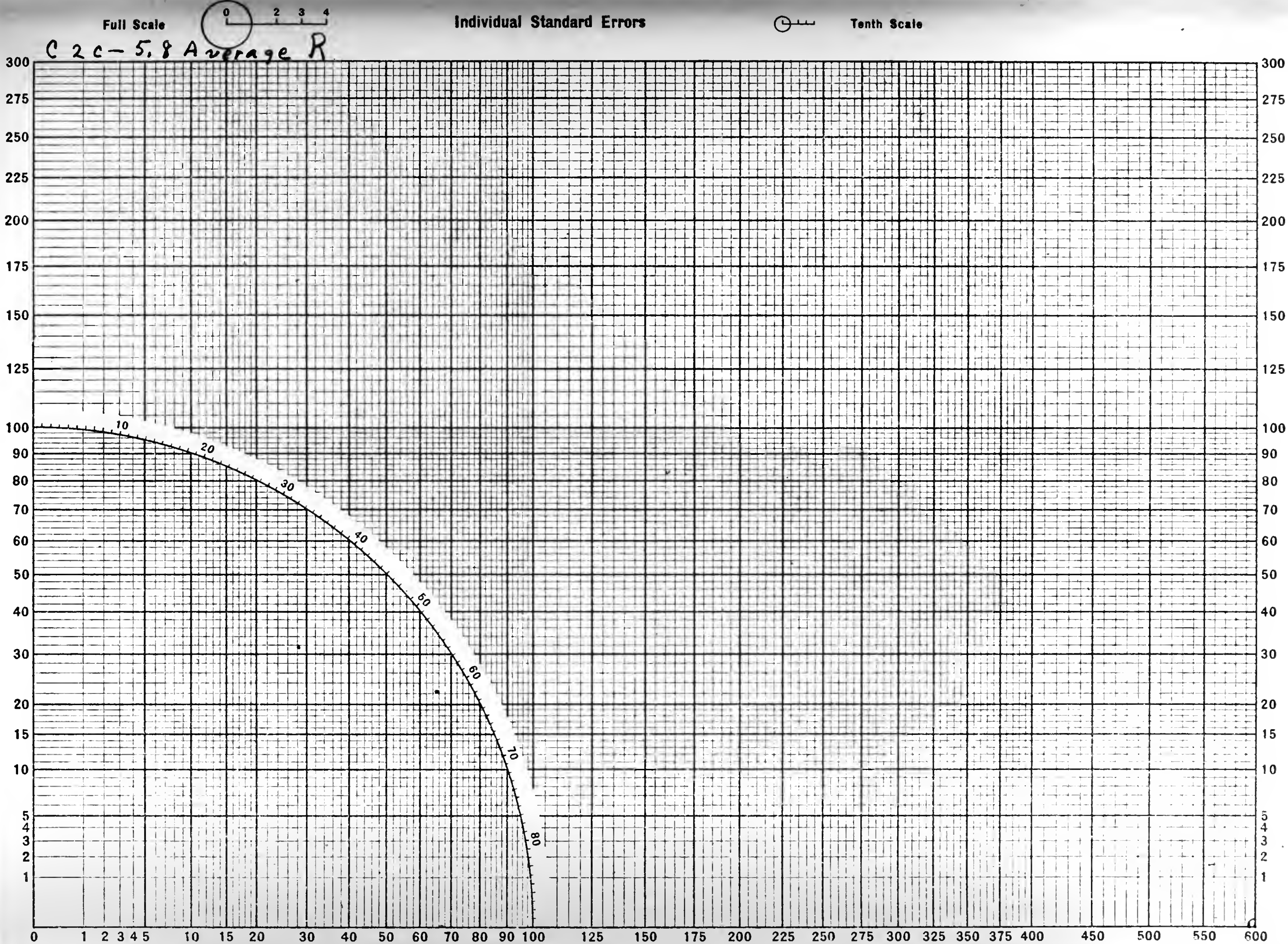
C2b—5.8 Average R



Full Scale Individual Standard Errors Tenth Scale

C 2c - 4.8 Average R



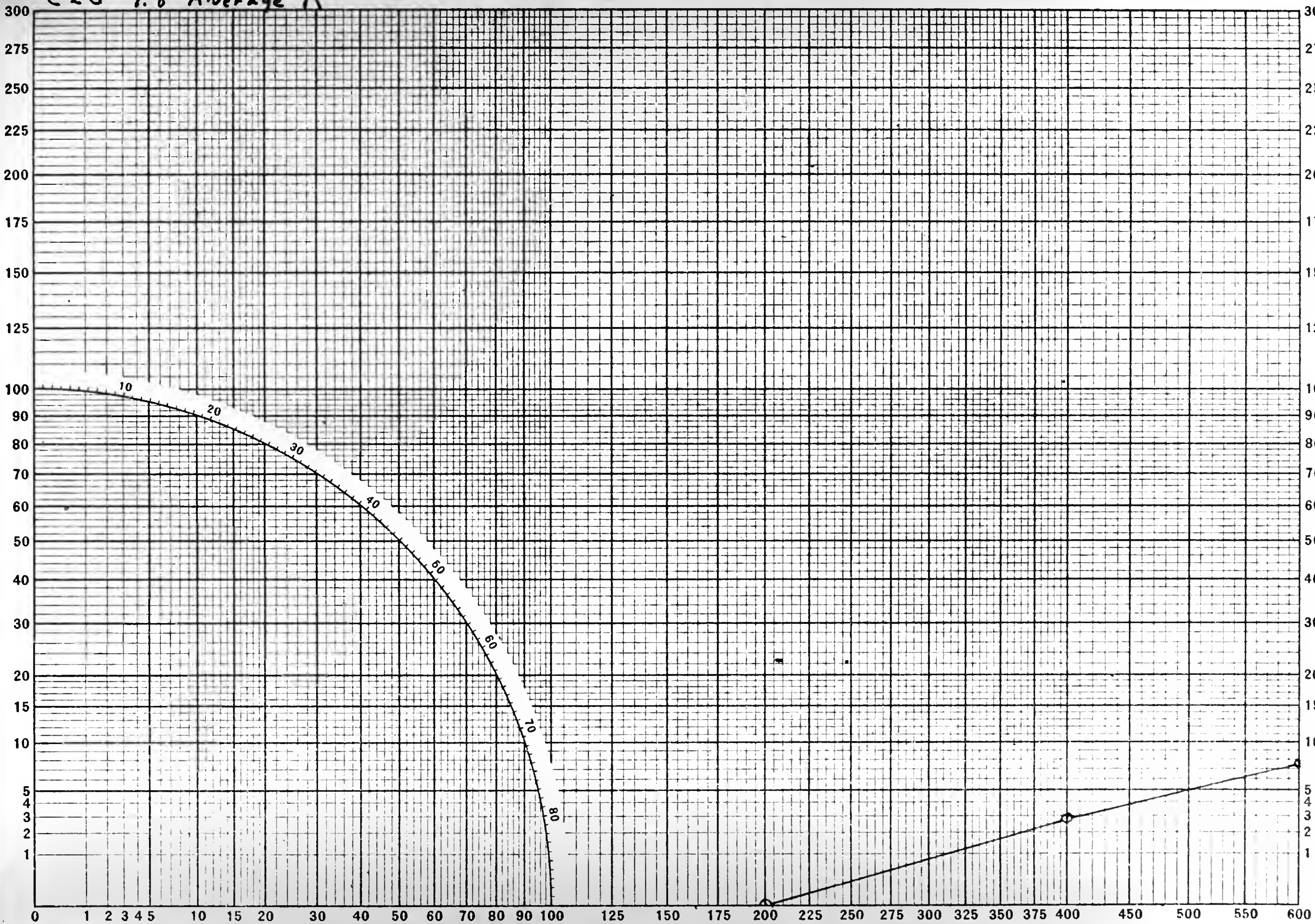

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2c – 5.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

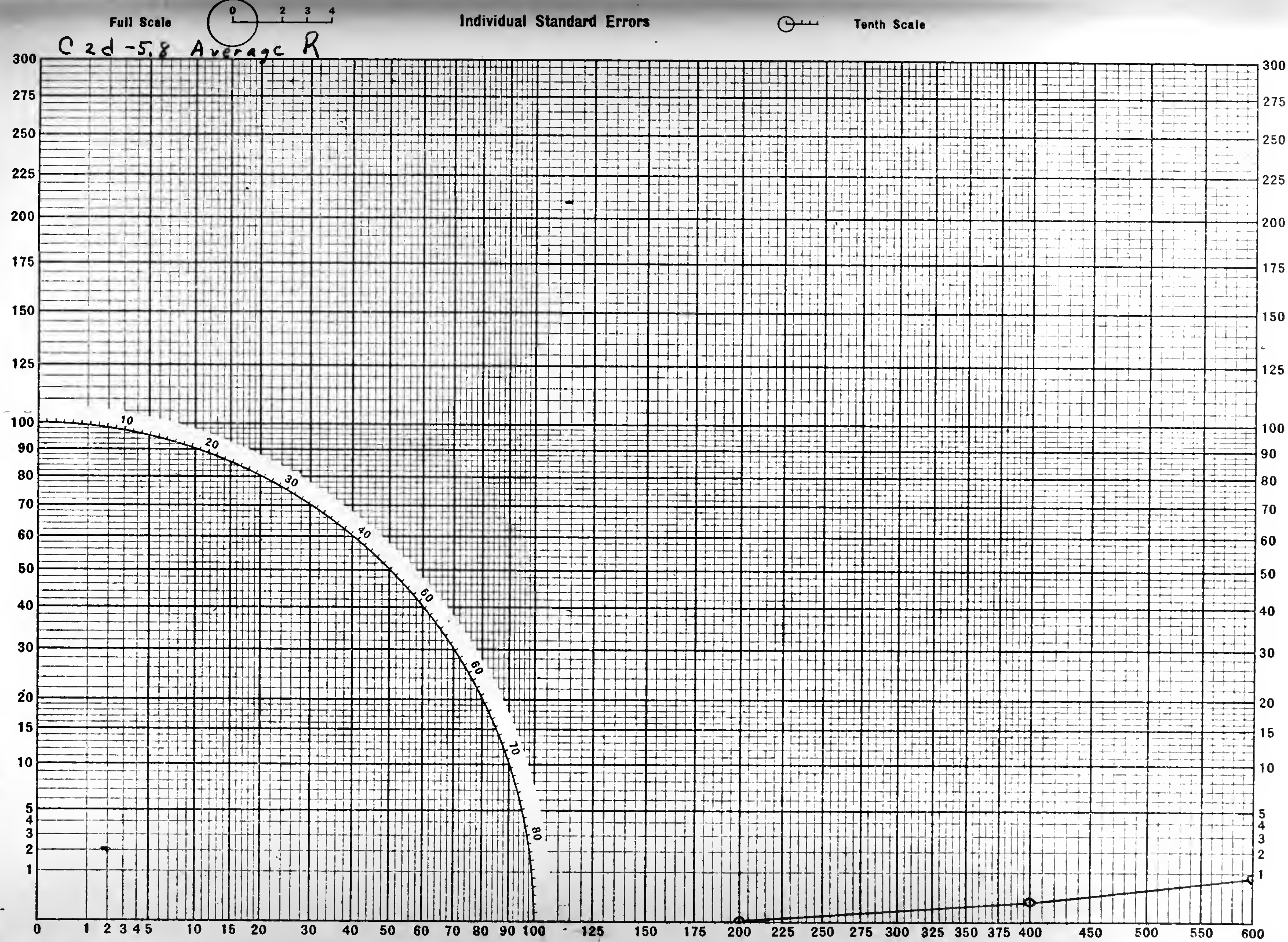
Full Scale

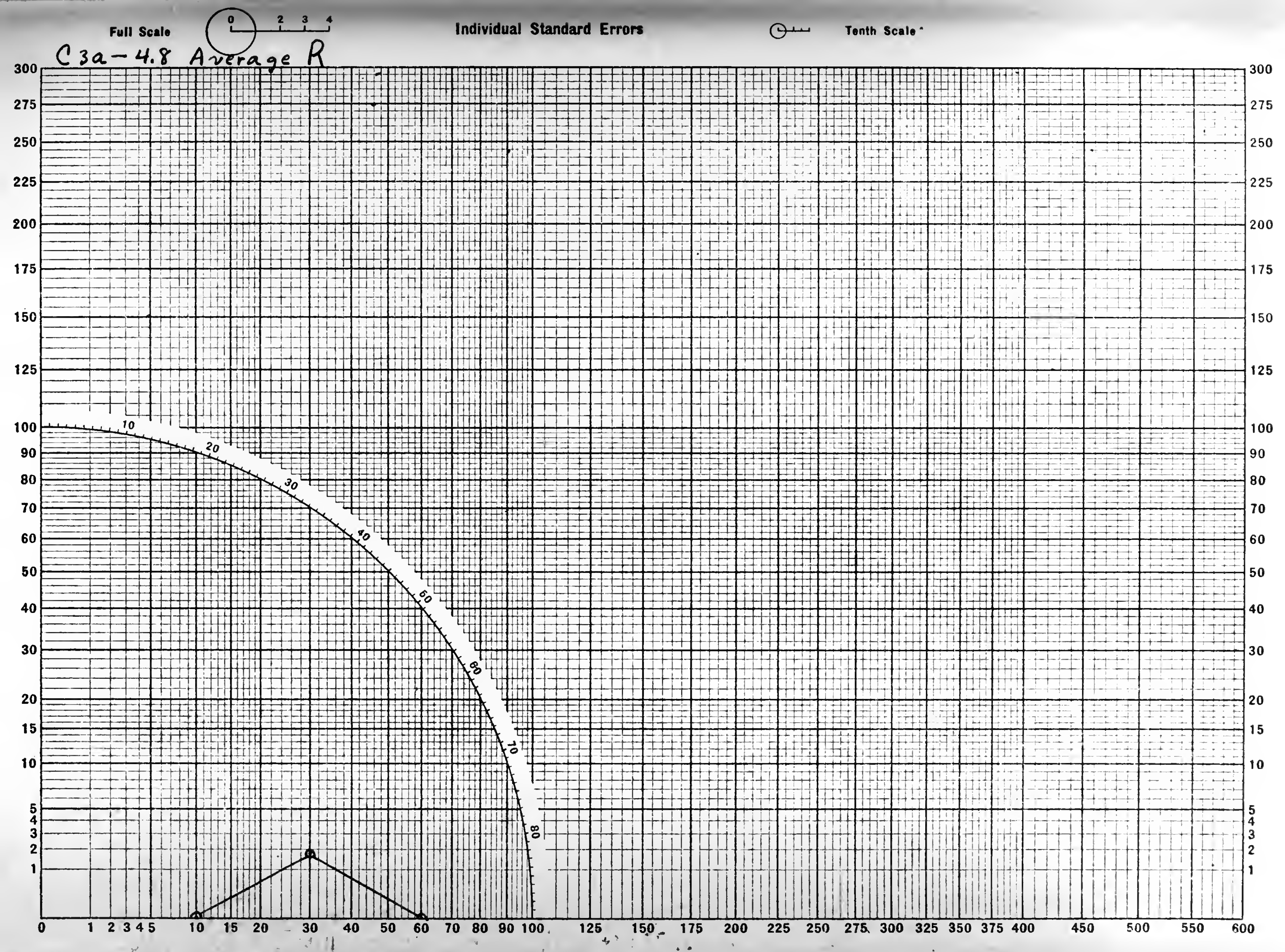
Individual Standard Errors

Tenth Scale

C2d-4.8 Average R




Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C 2d -5.8 Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80



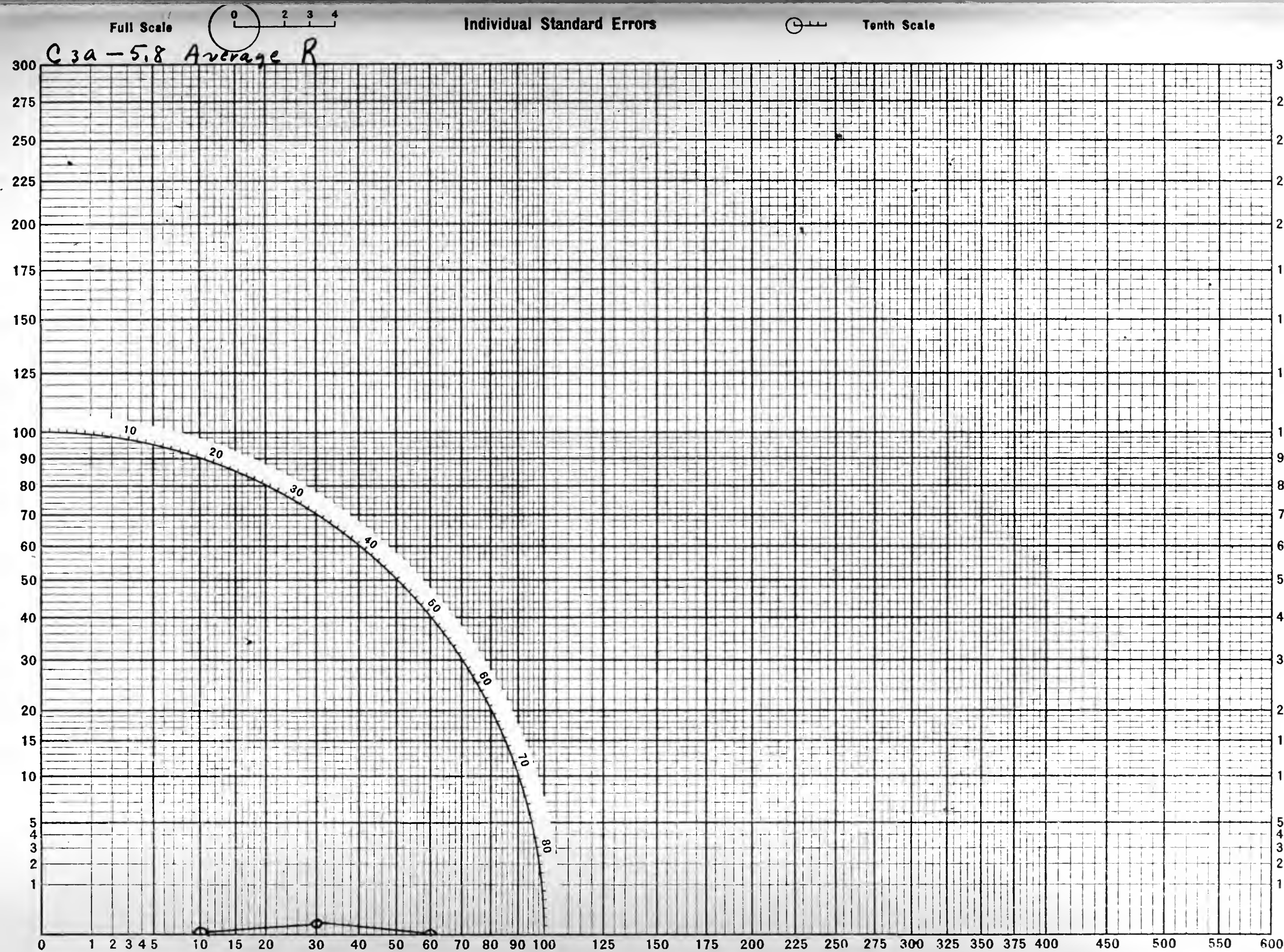
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3a-4.8 Average R

Full Scale

Individual Standard Errors

Tenth Scale

C 3a — 5.8 Average R

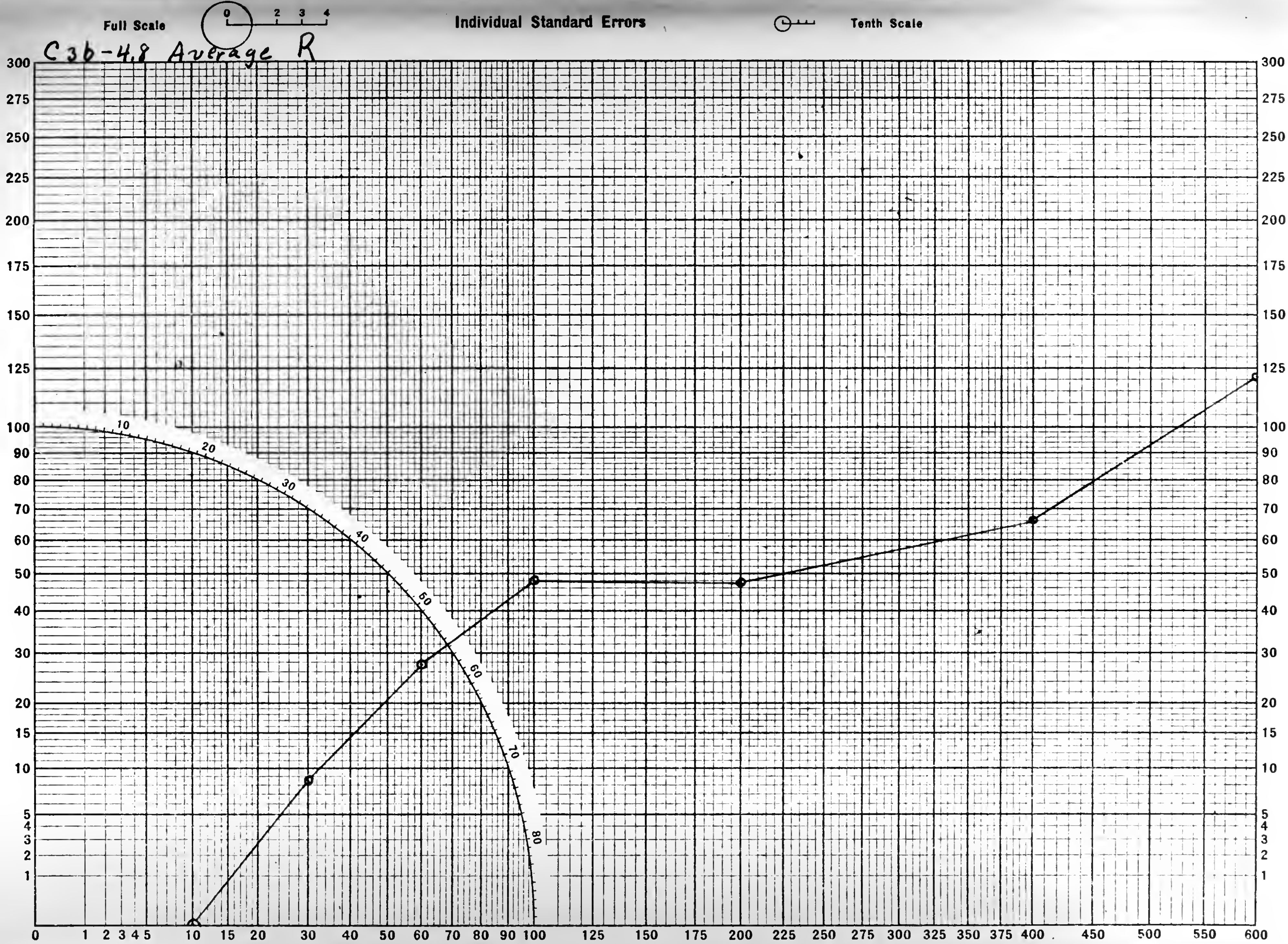


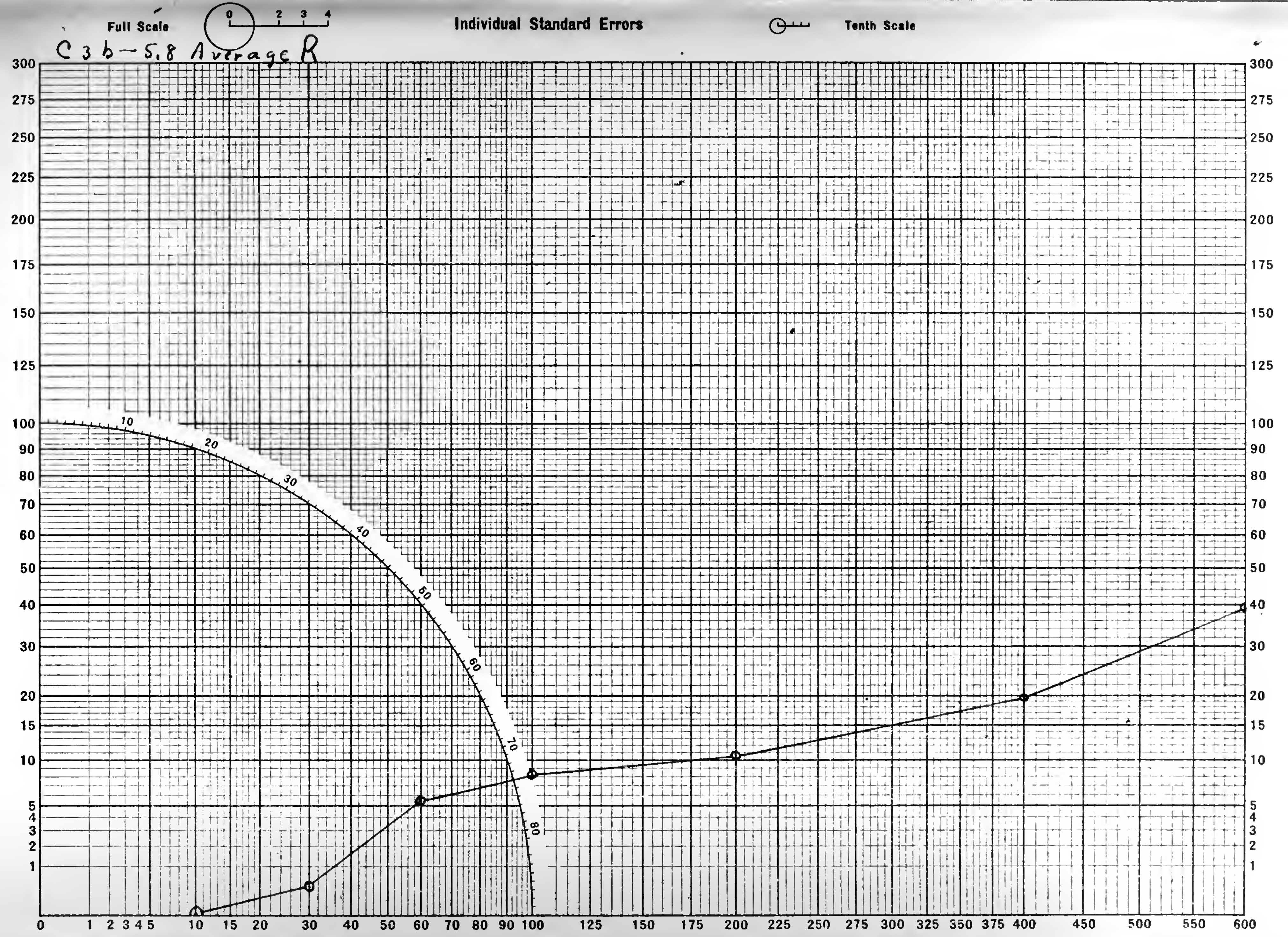
Full Scale

Individual Standard Errors

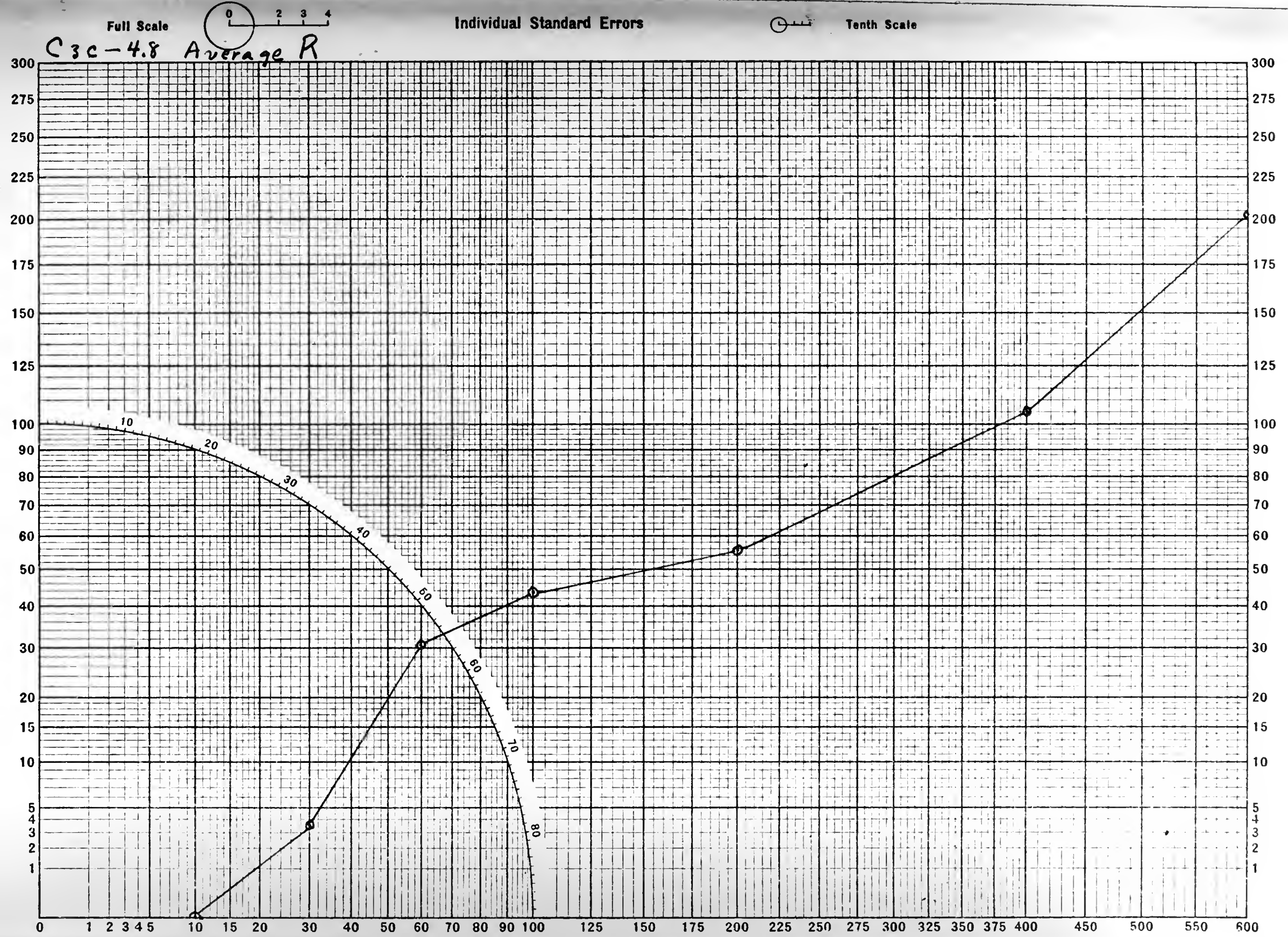
Tenth Scale

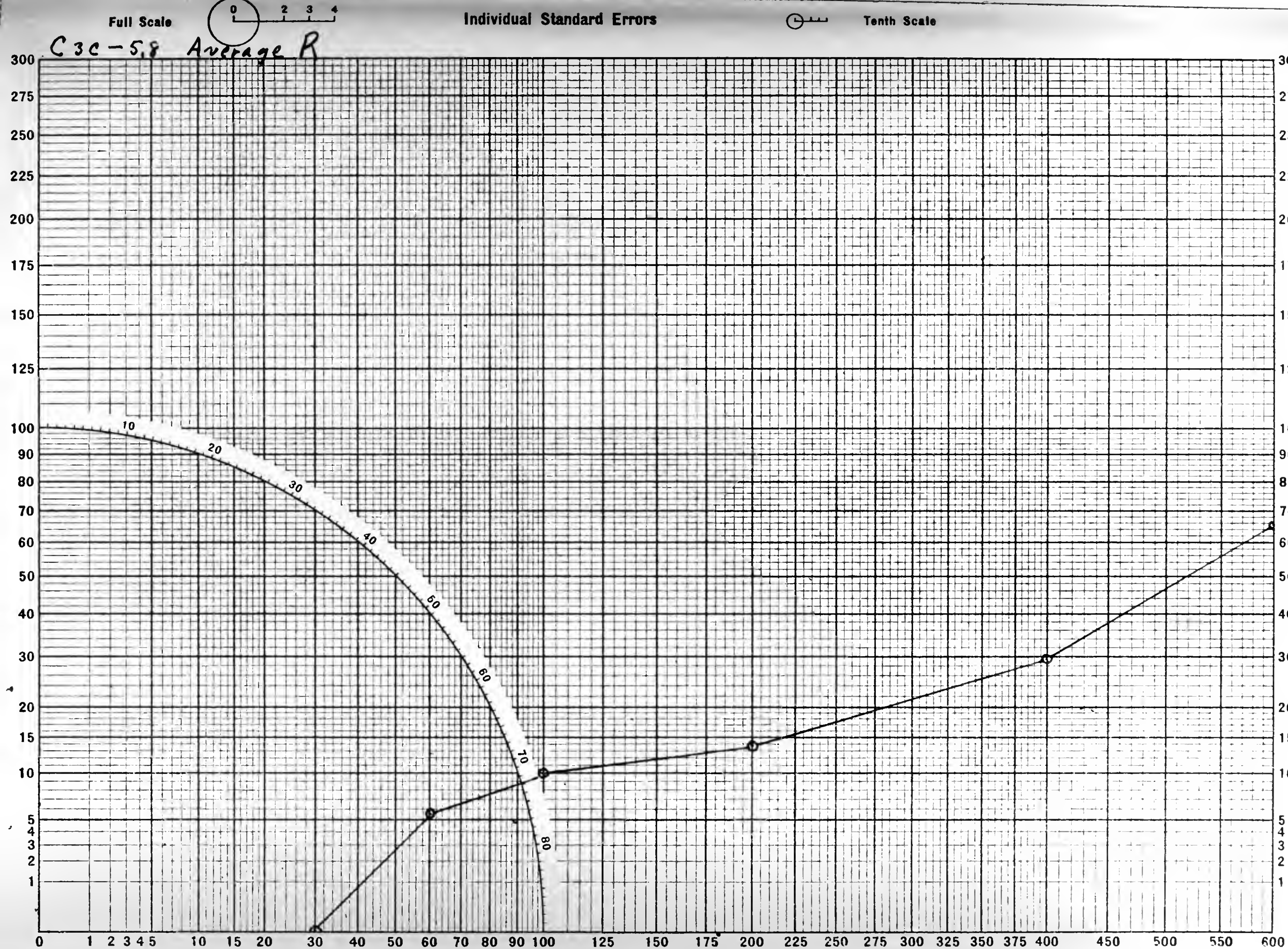
C36-4.8 Average R

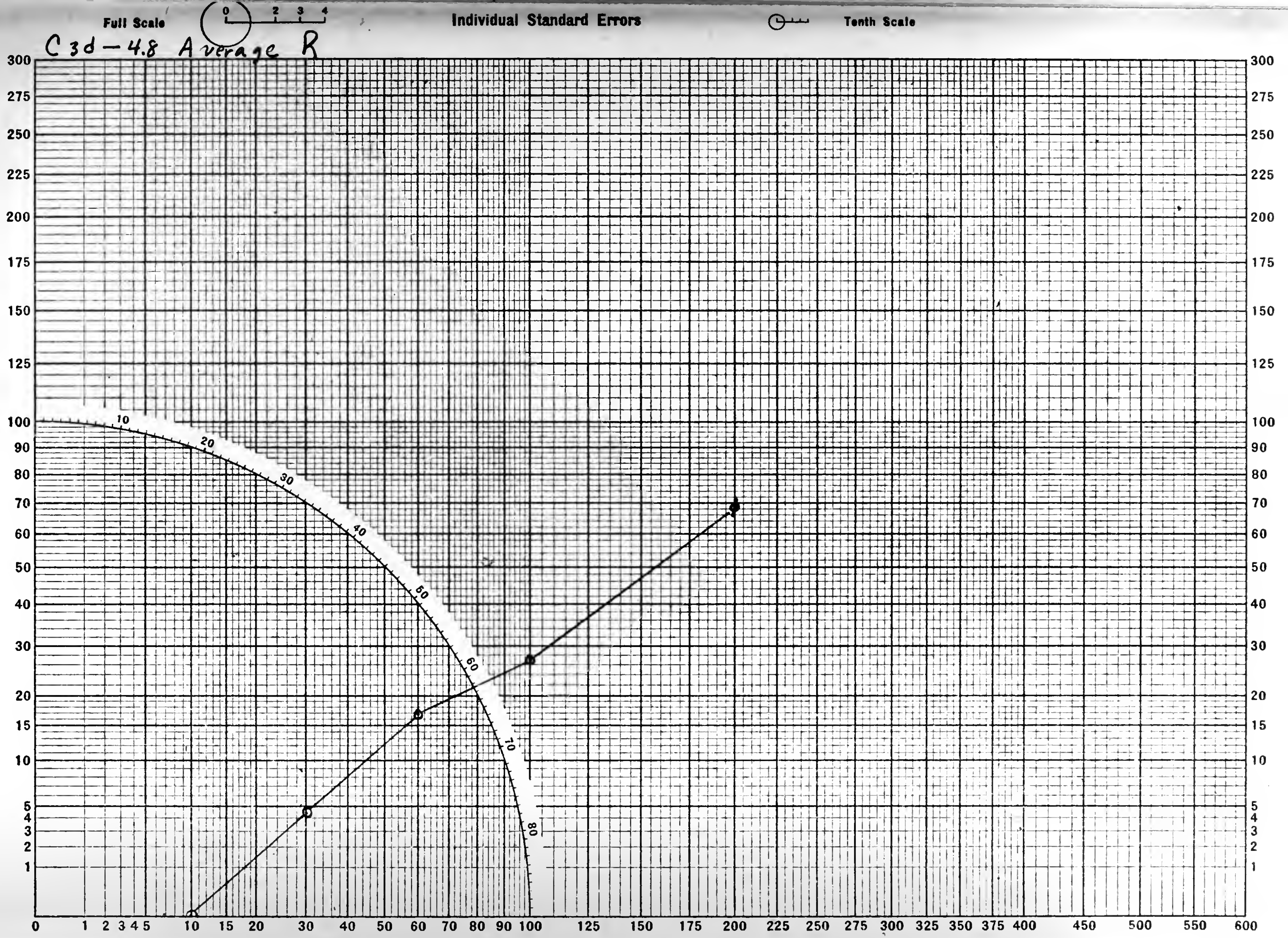


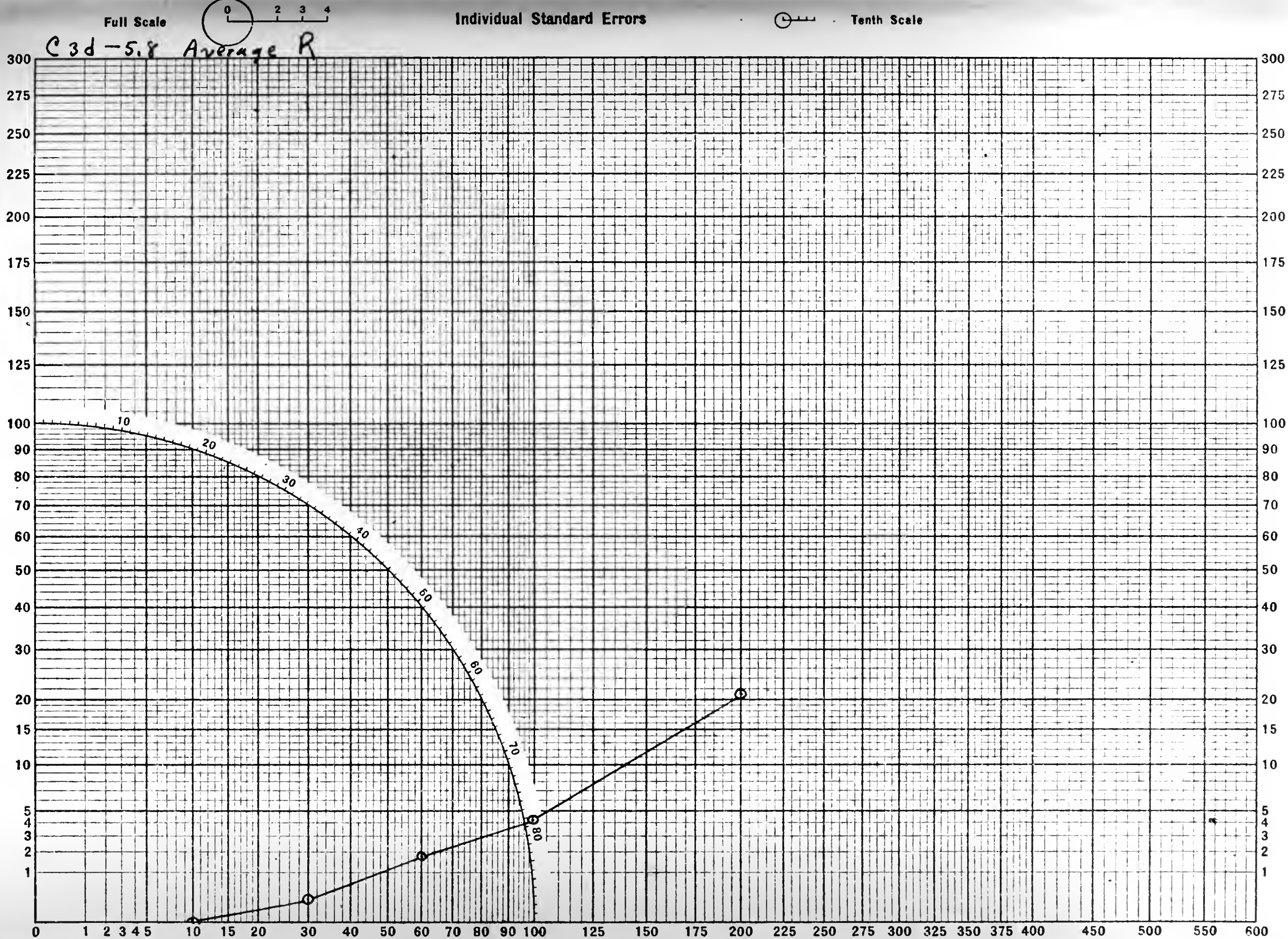


Full Scale
Individual Standard Errors
Tenth Scale
C 3 b — 5.8 Average R


Full Scale
Individual Standard Errors
Tenth Scale
C3c-4.8 Average R

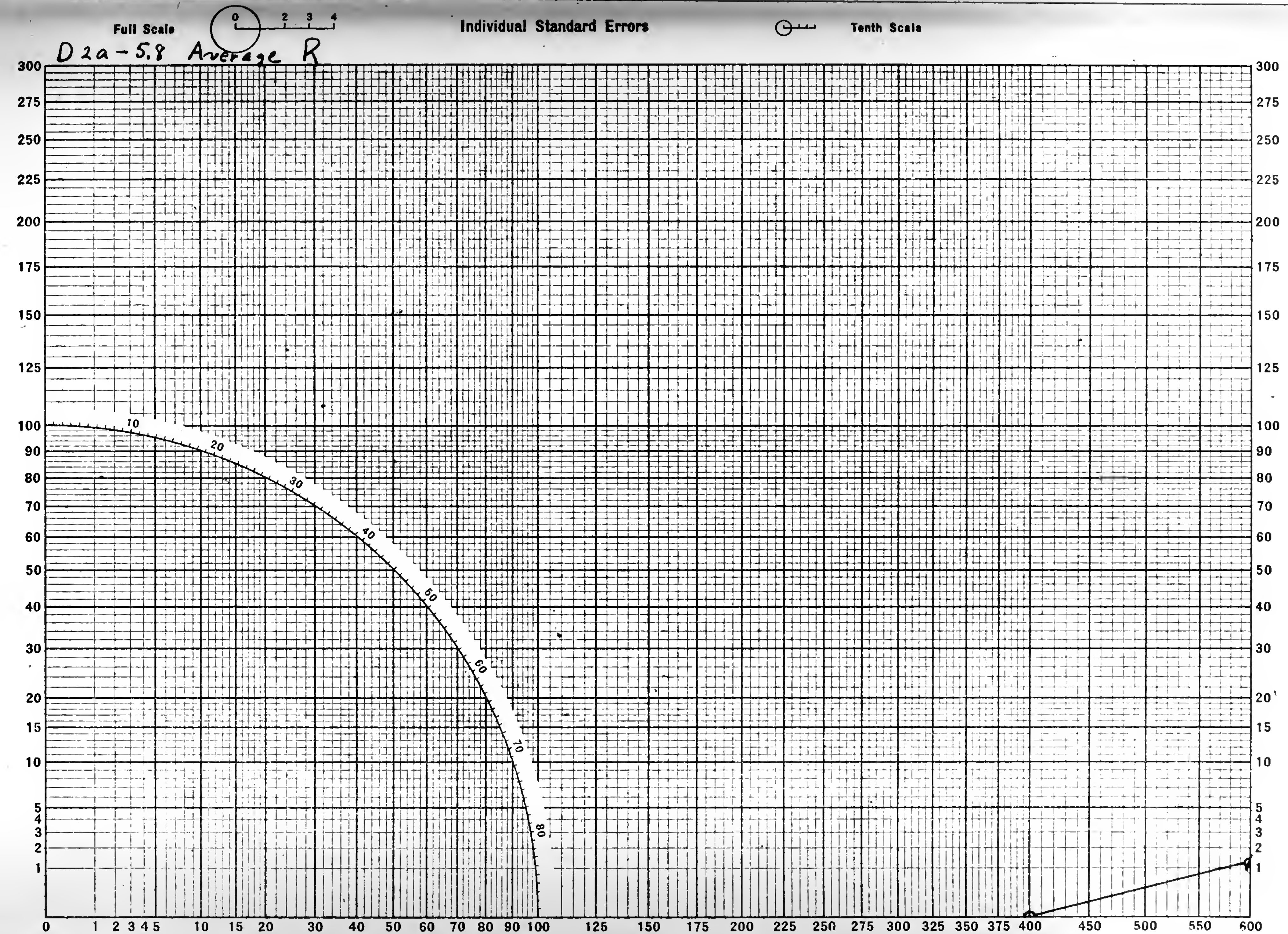

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3c-5.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

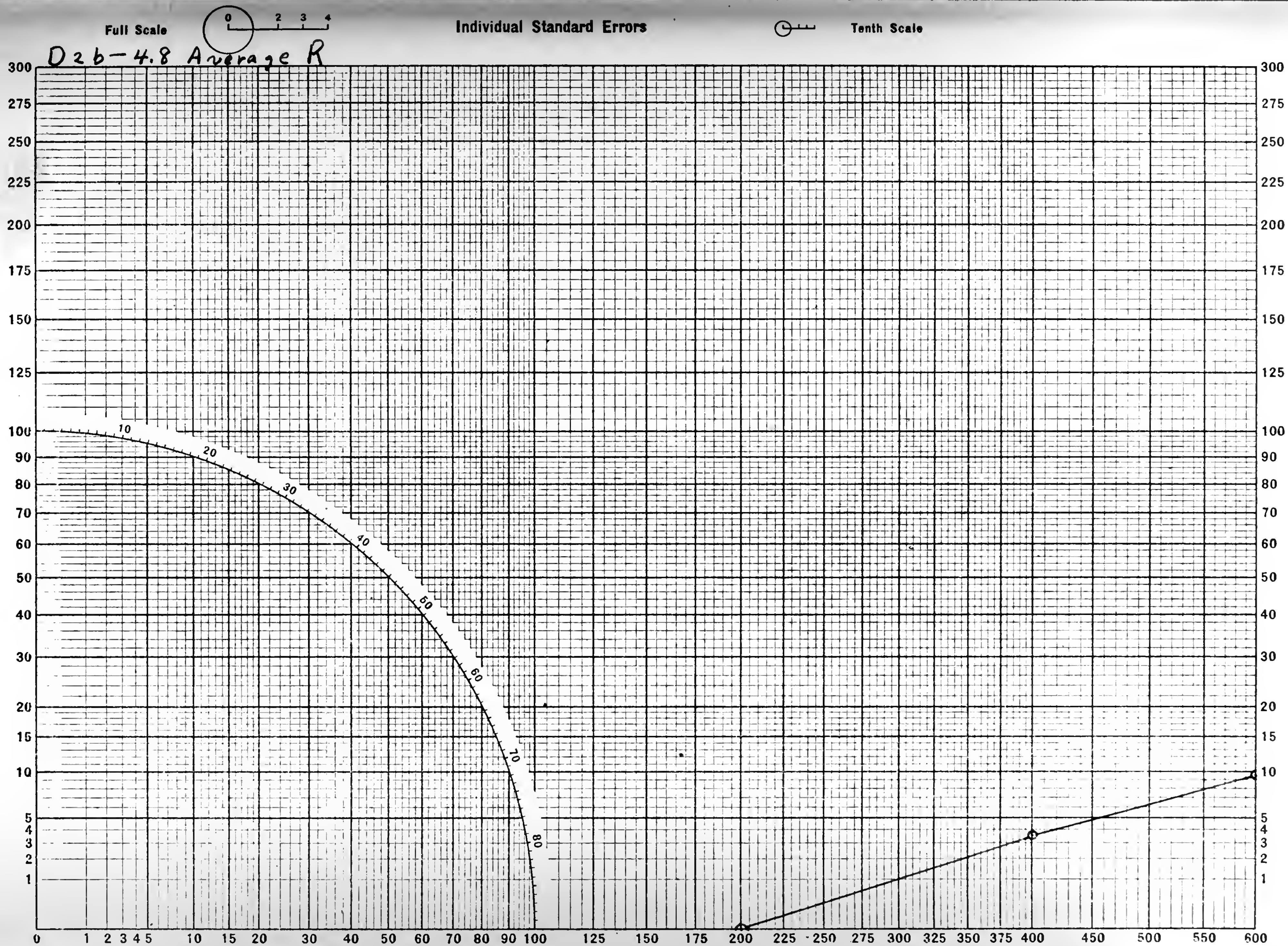

Full Scale
Individual Standard Errors
Tenth Scale
C 3d – 4.8 Average R



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3d-5.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

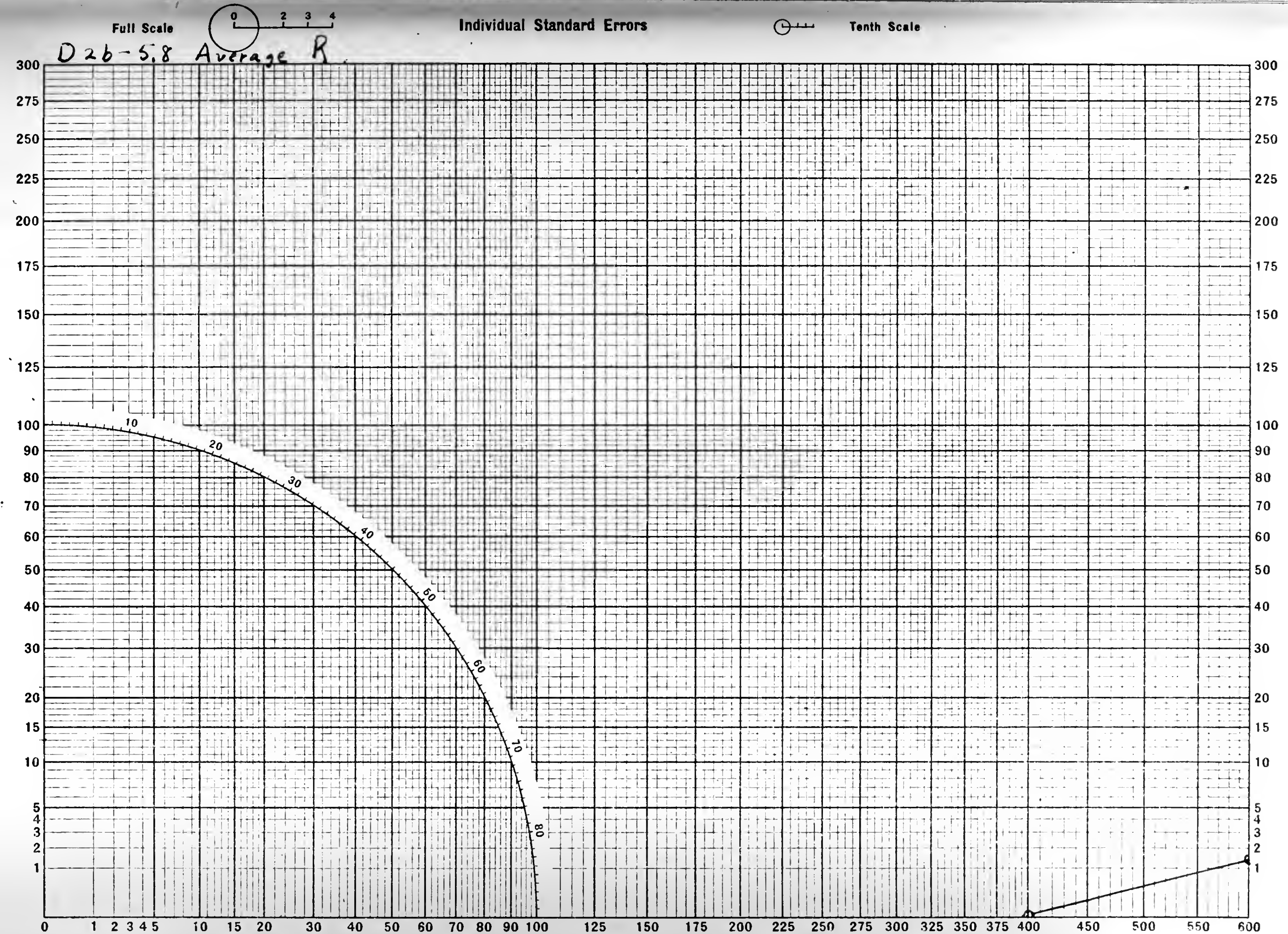

Full Scale
Individual Standard Errors
Tenth Scale
D2a-4.8 Average R


Full Scale
Individual Standard Errors
Tenth Scale
D2a-5.8 Average R



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2b-4.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

D2b-5.8 Average R

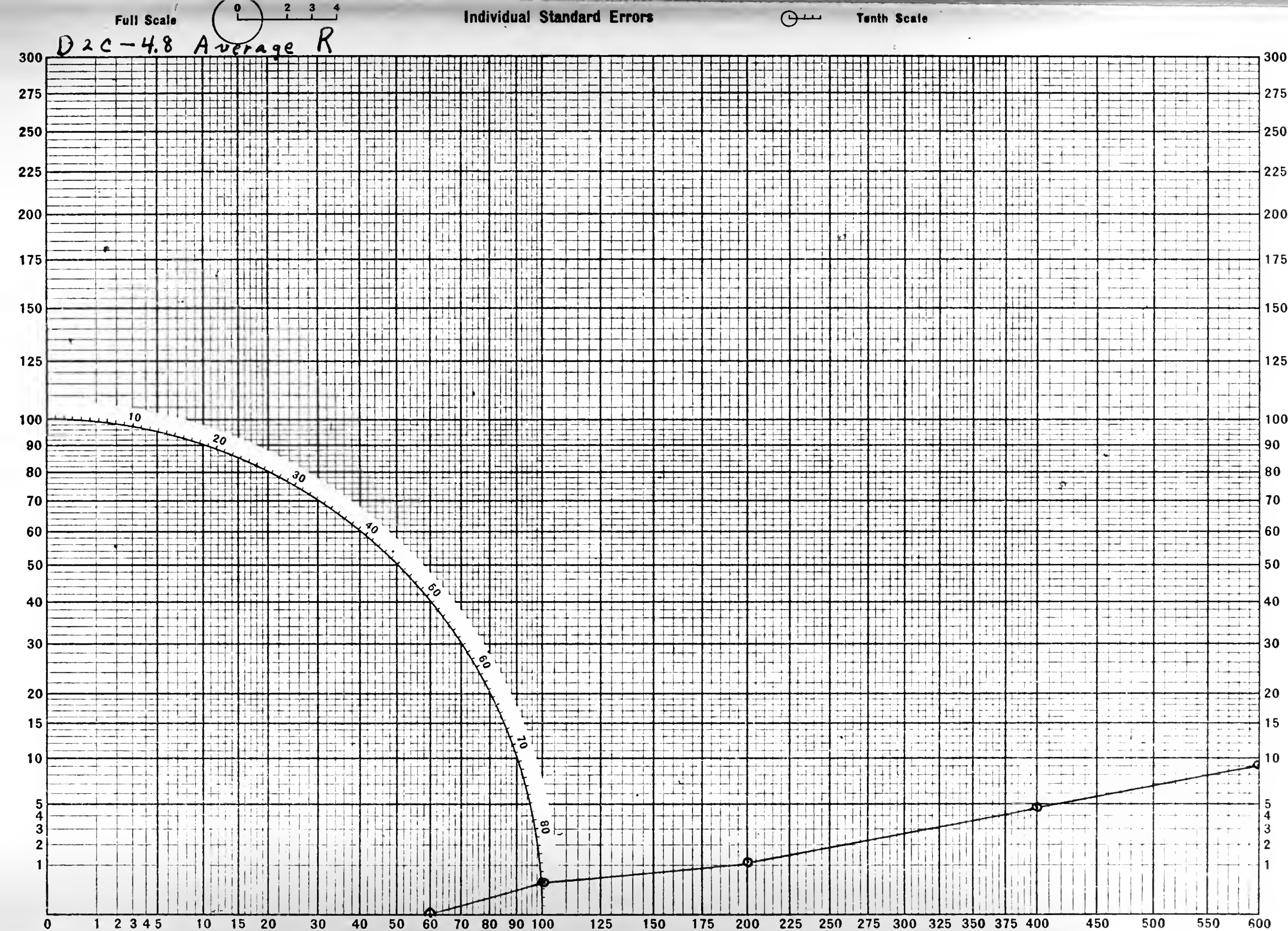


Full Scale

Individual Standard Errors

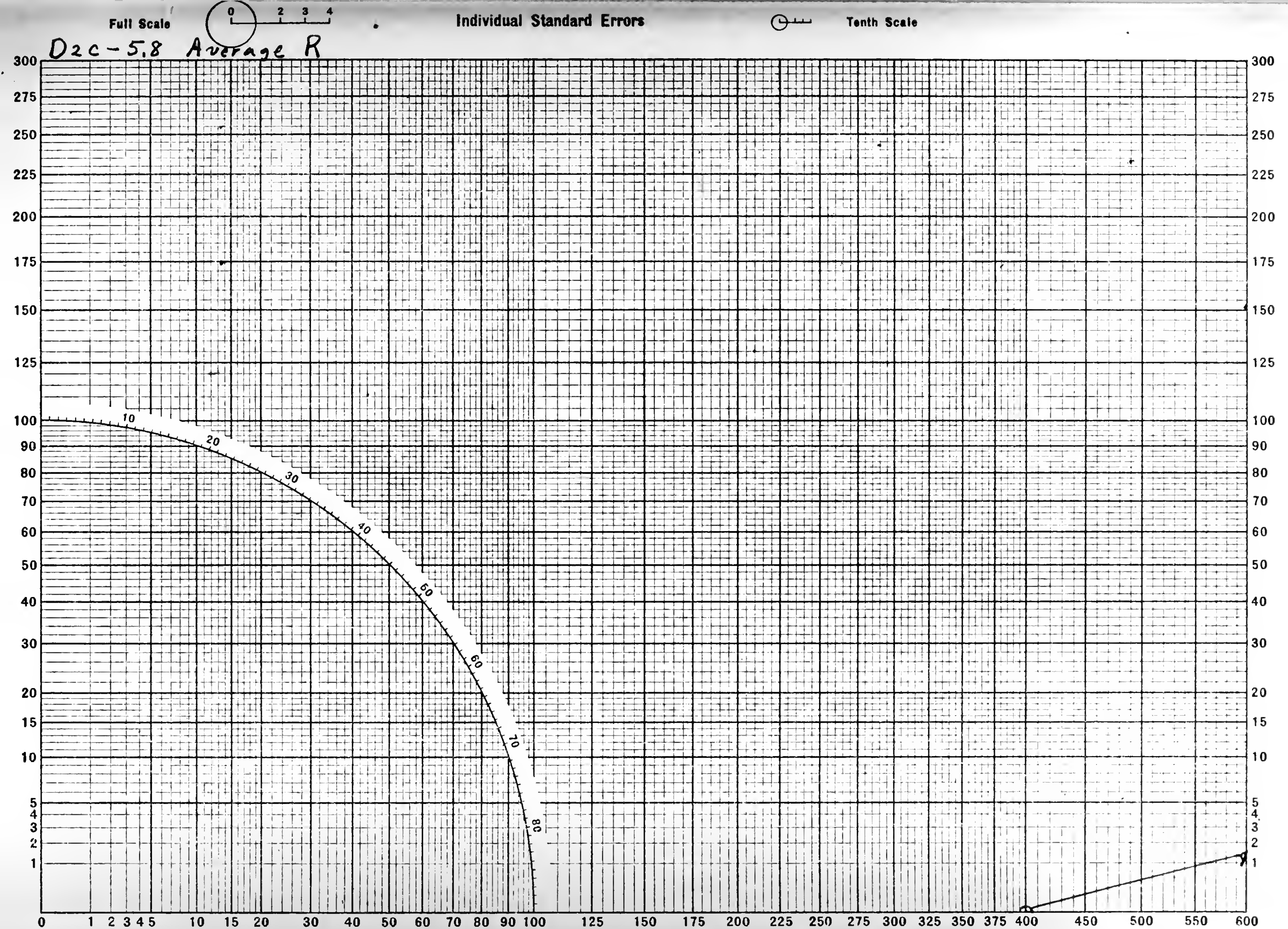
Tenth Scale

D2C-4.8 Average R



Full Scale Individual Standard Errors Tenth Scale

D2c - 5.8 Average R

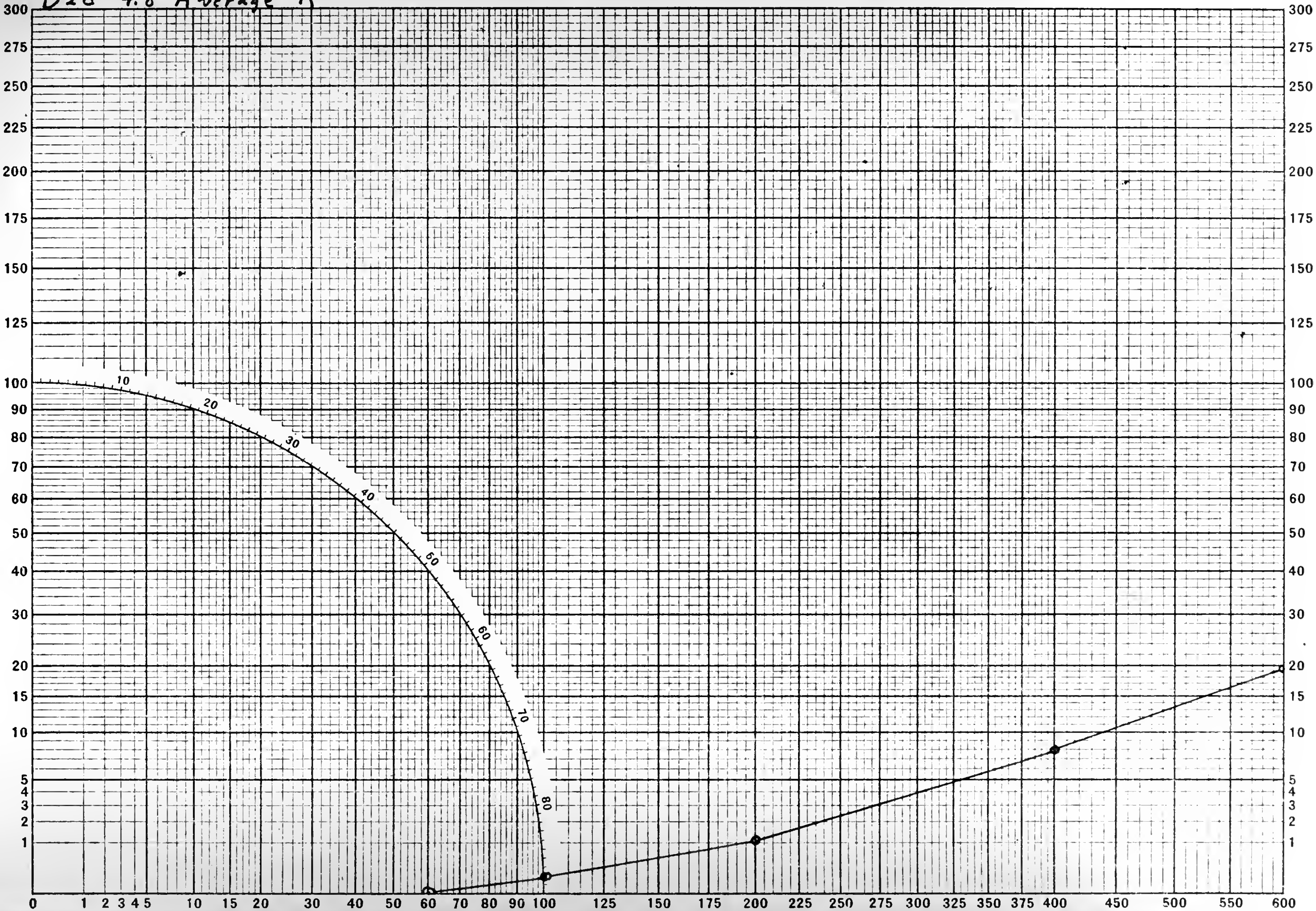


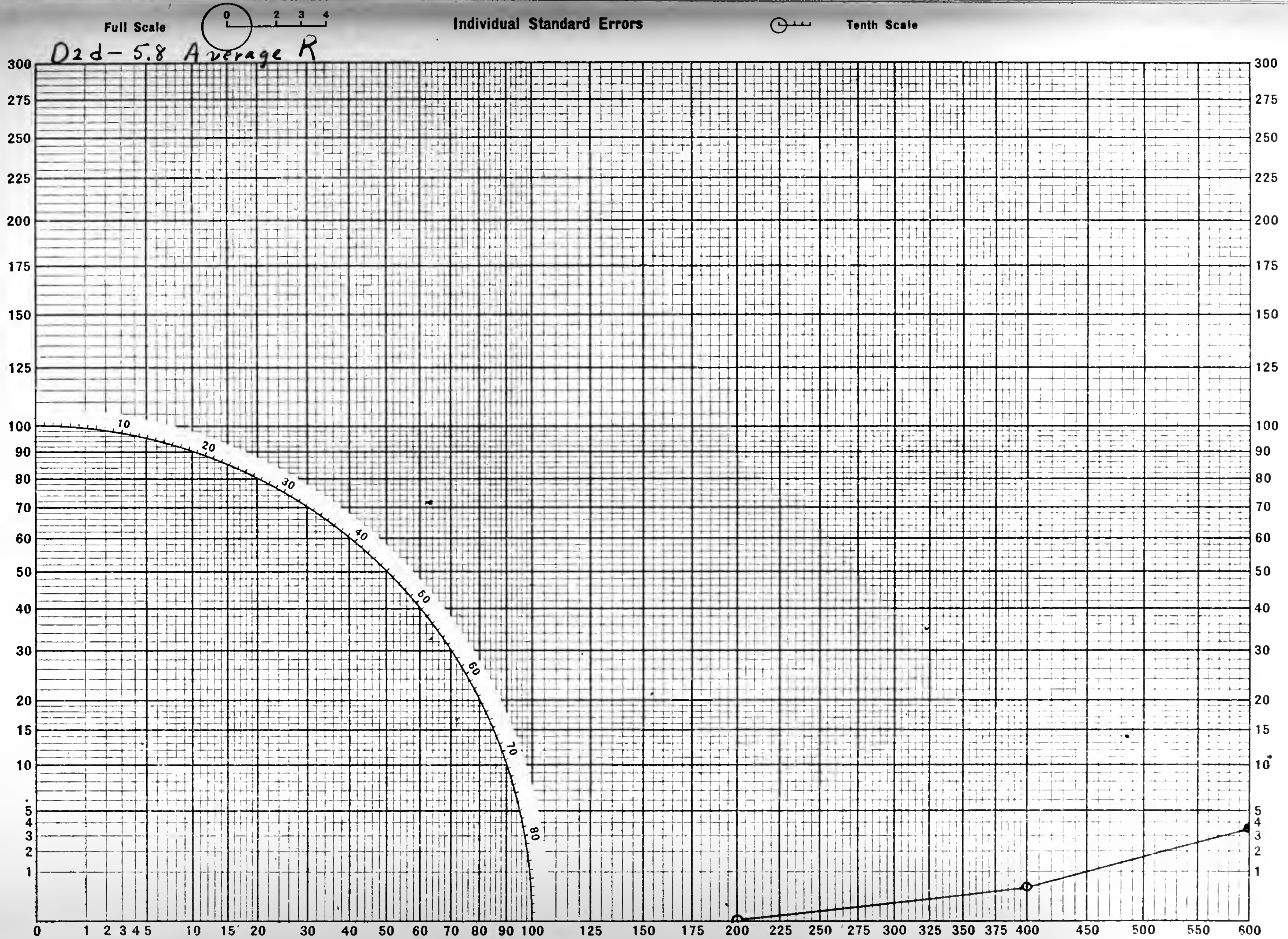
Full Scale

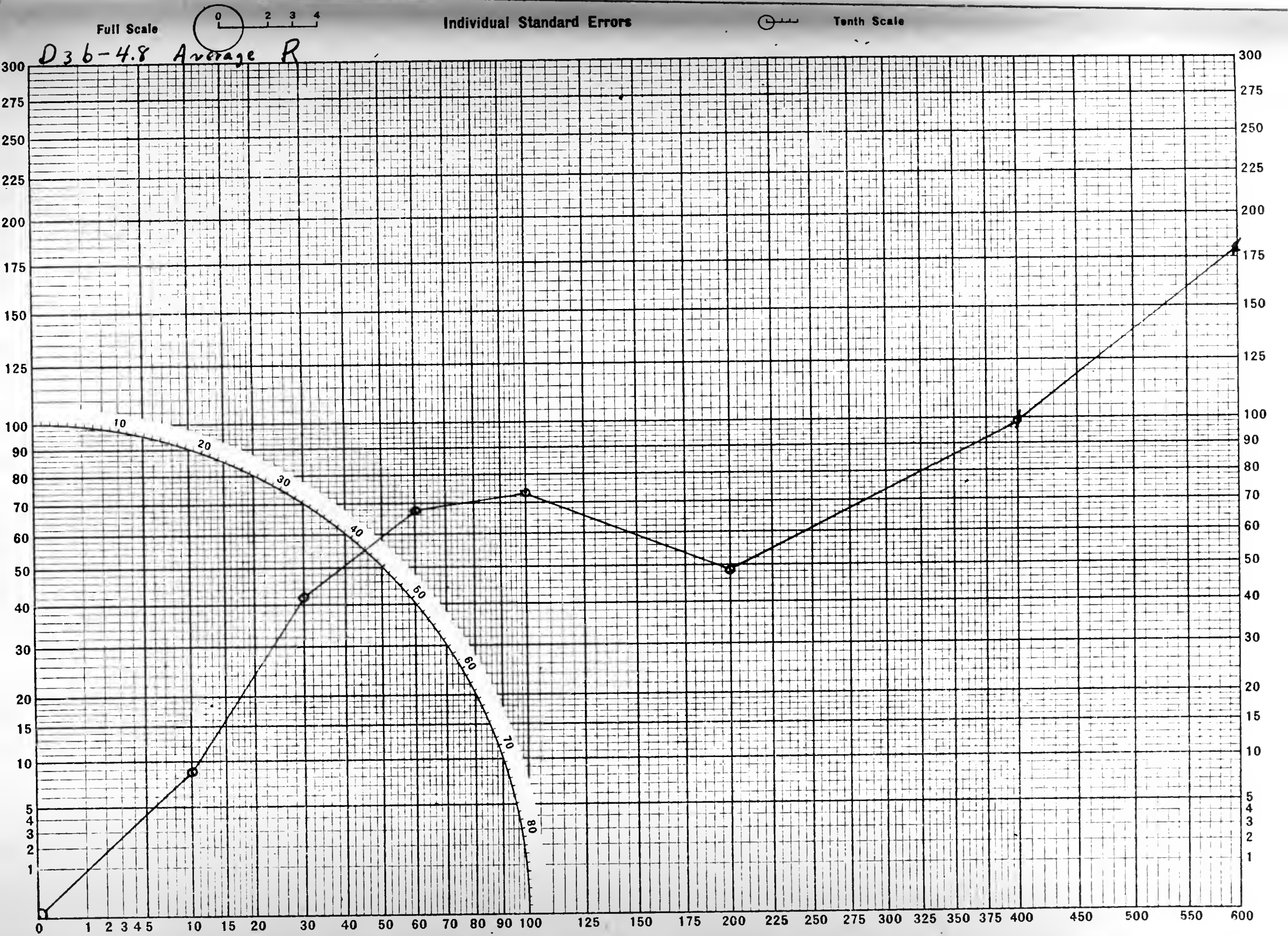
Individual Standard Errors

Tenth Scale

D2d-4.8 Average R

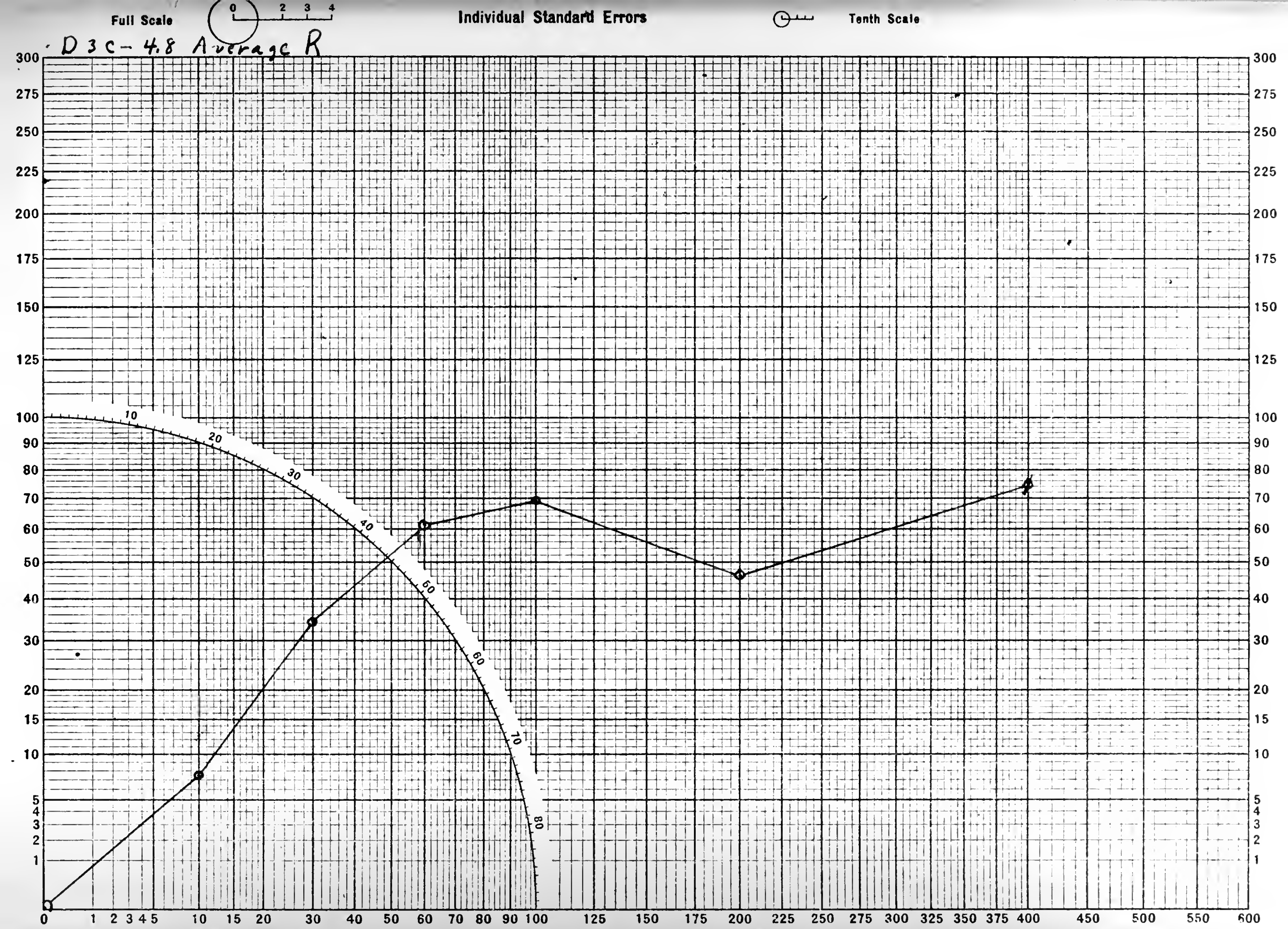



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2d-5.8 Average R
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D3b-4.8 Average R


Full Scale
Individual Standard Errors
Tenth Scale
D3b-5.8 Average R



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D 3 C - 4.8 Average R

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D3c-5.8' Average R
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10
15
20
30
40
50
60
70
80
90
100
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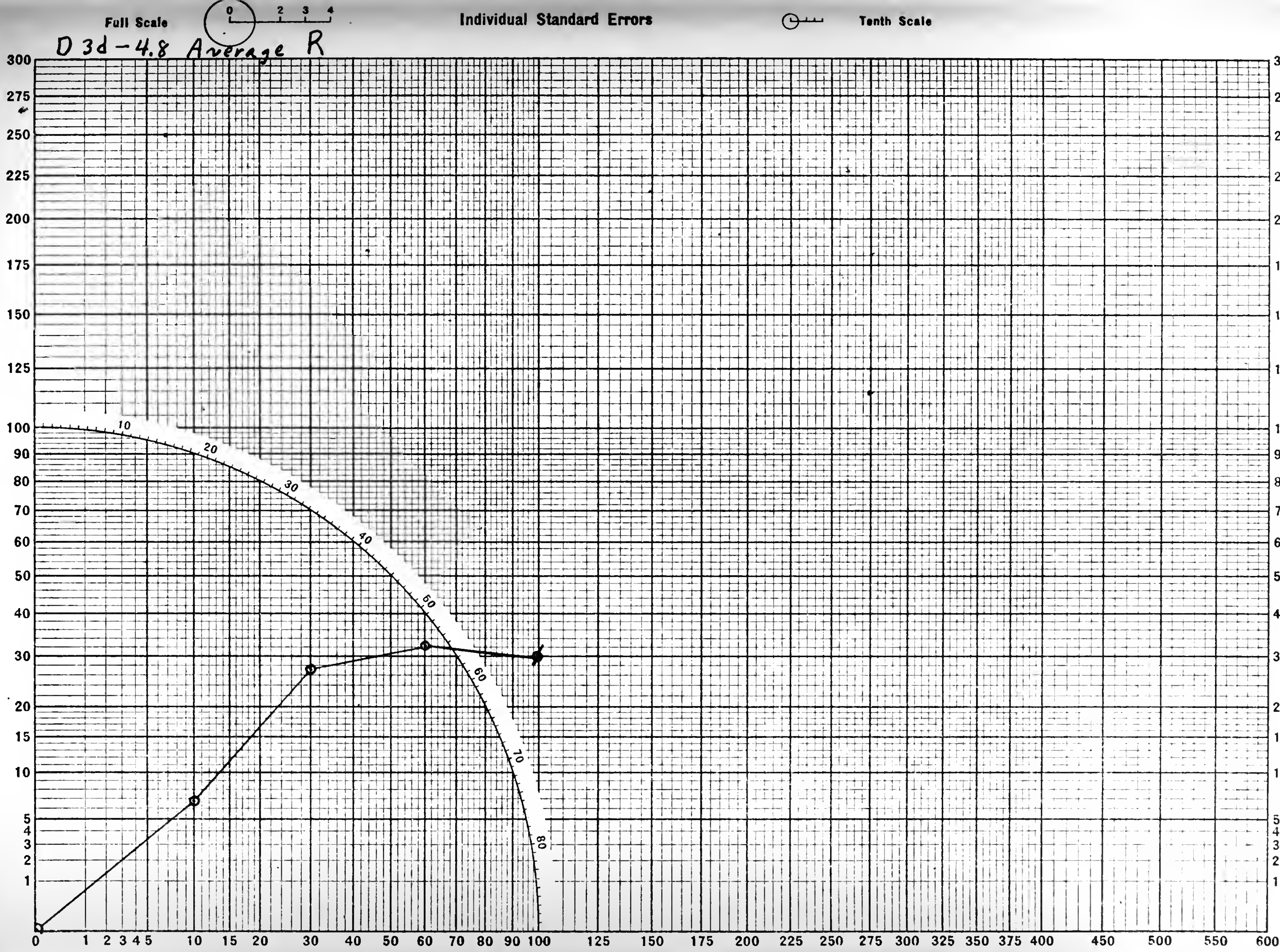
400
450
500
550
600



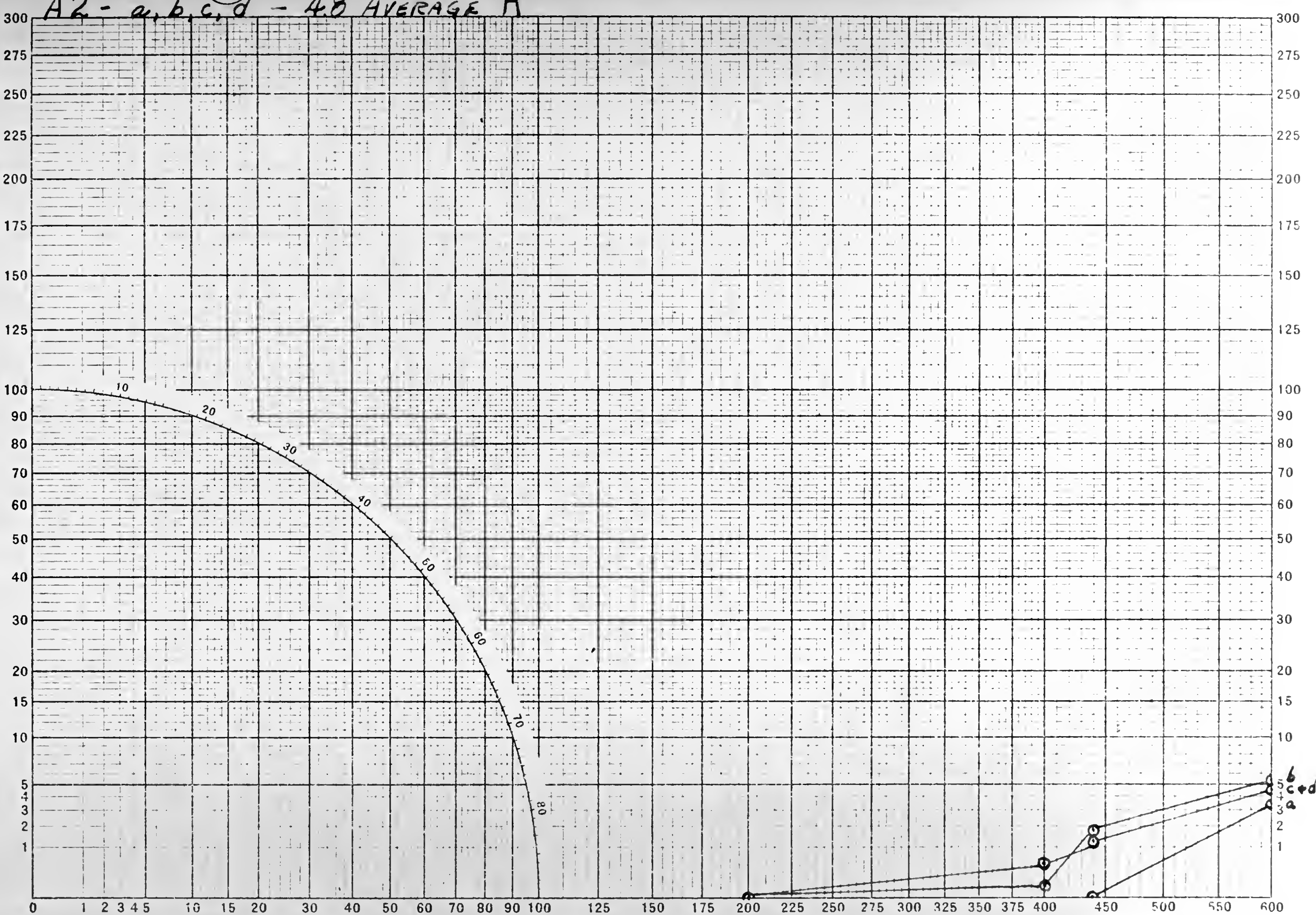
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D 3d - 4.8 Average R

Full Scale
0 2 3 4
Individual Standard Errors
Tanth Scale
D3d-5.8 Average R

AVERAGE RESISTANCE, COMPARING
FIELD INTENSITY AND OPERATING
CATHODE CURRENT EFFECTS

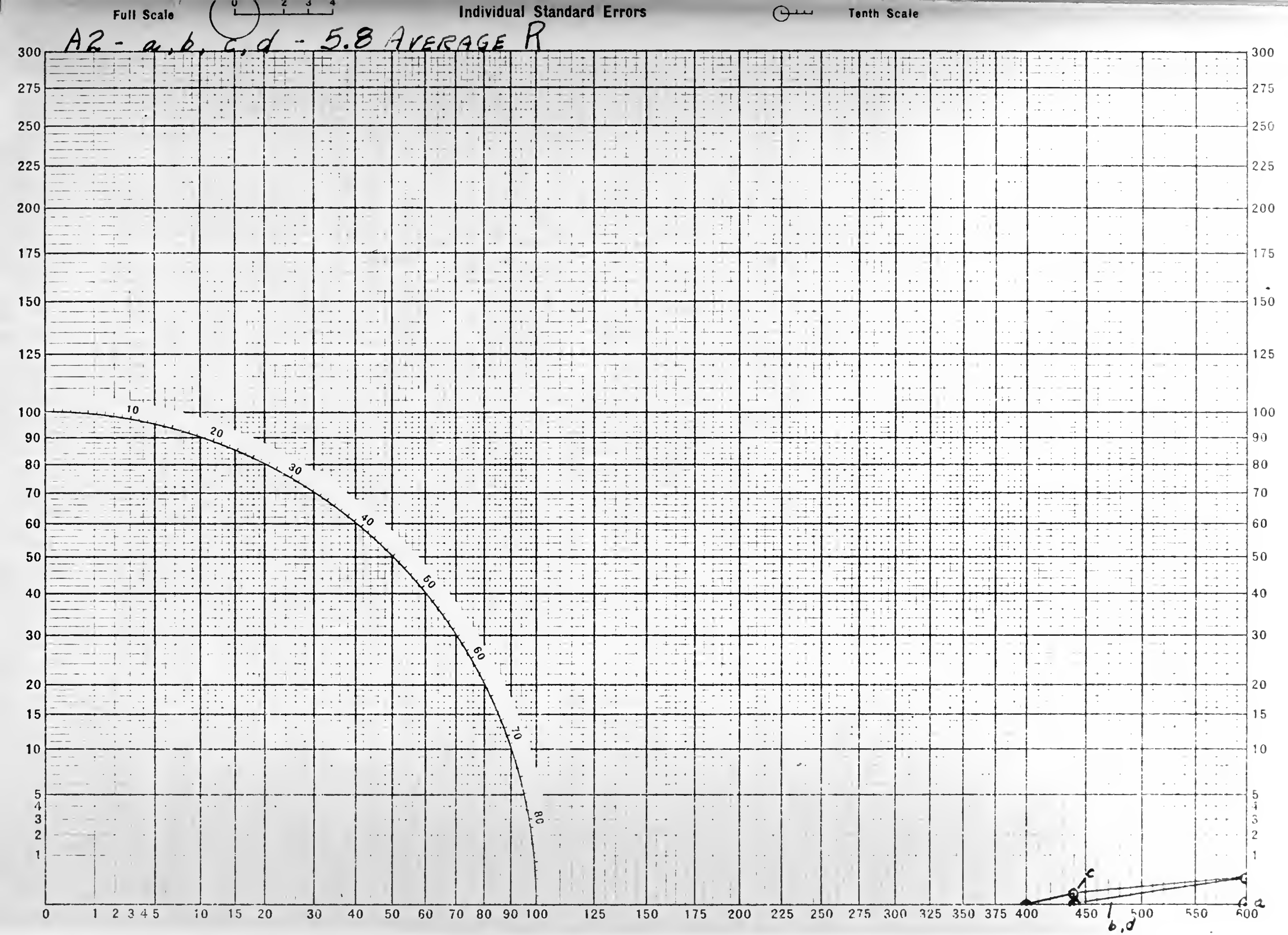
Full Scale Individual Standard Errors Tenth Scale

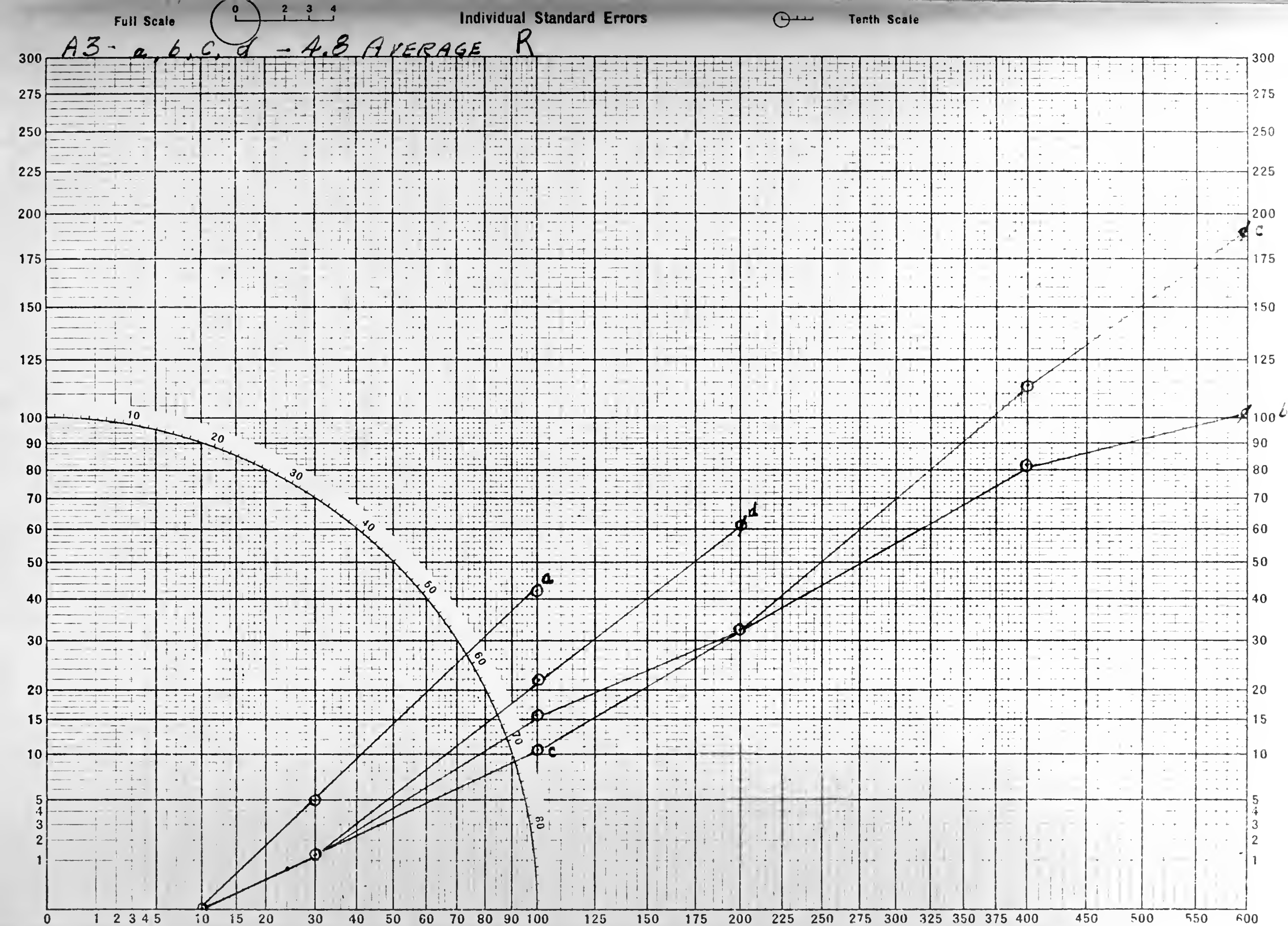
A2 - a, b, c, d - 48 AVERAGE R



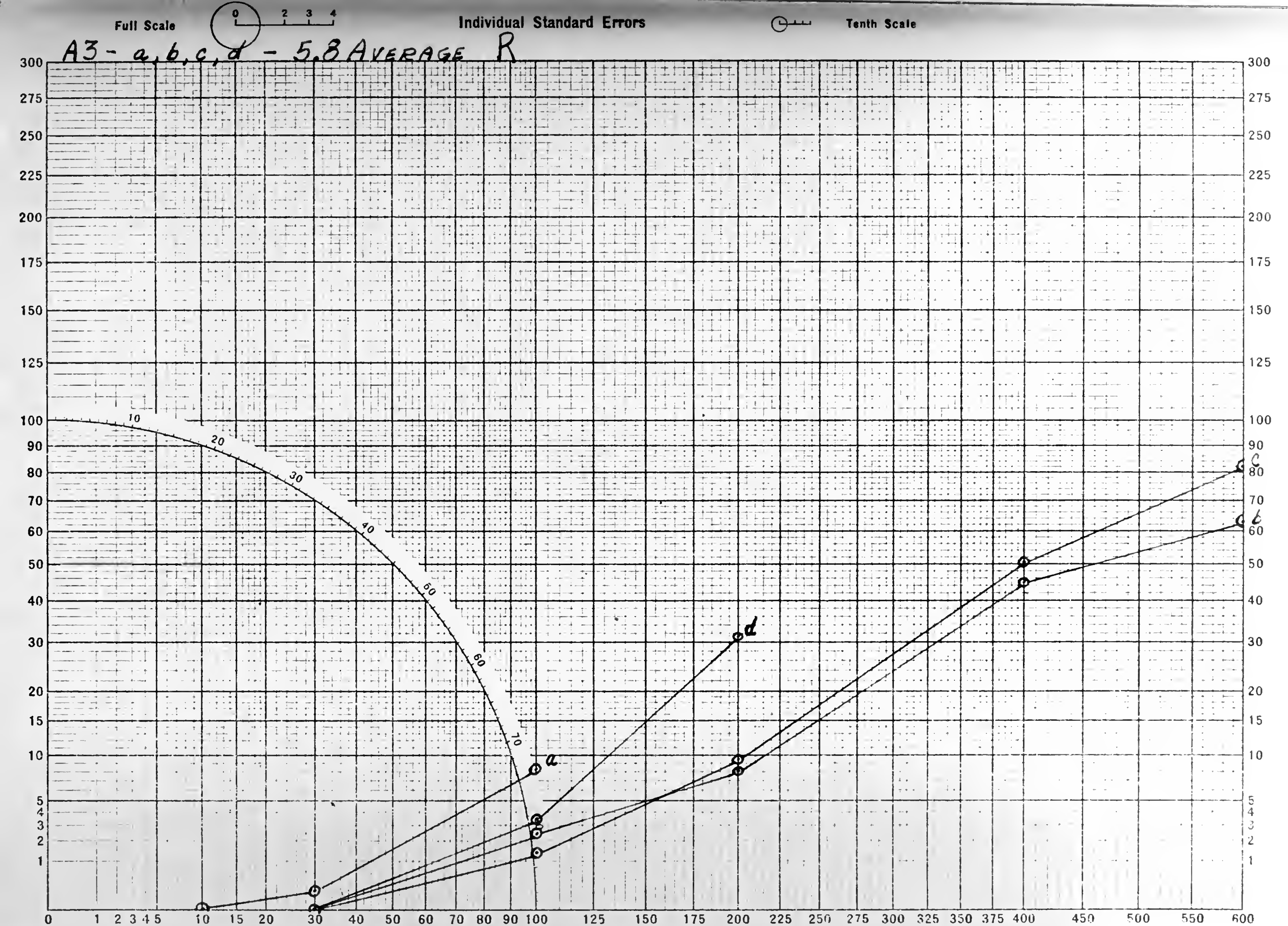
Full Scale   Individual Standard Errors   Tenth Scale

A2 - a, b, c, d - 5.8 AVERAGE R





Full Scale
0
2
3
4
Individual Standard Errors
Tenth Scale
A3 - a, b, c, d - 4.8 AVERAGE R
a
b
c
d



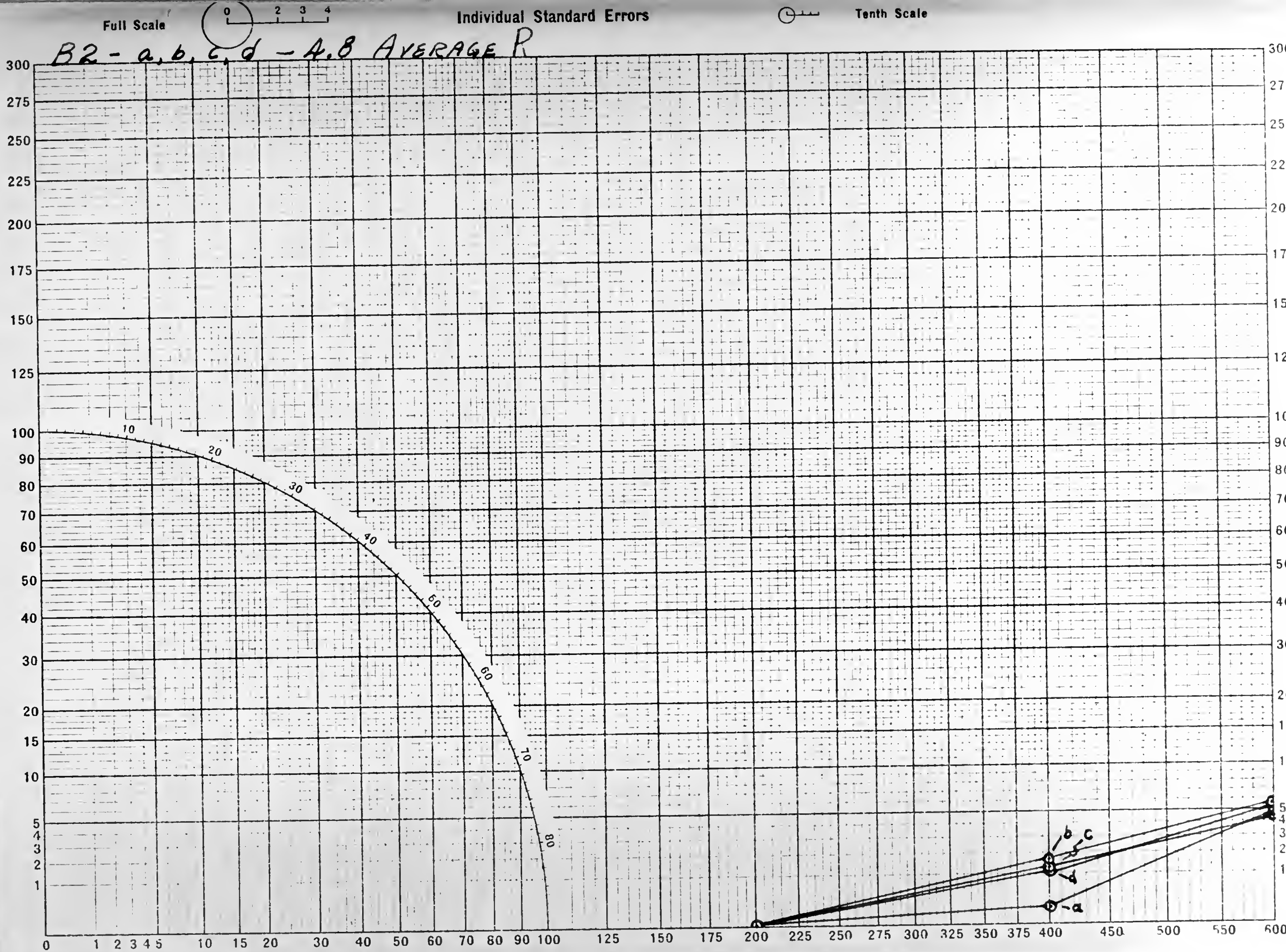
Full Scale
Individual Standard Errors
Tenth Scale
A3 - a, b, c, d - 5.8 AVERAGE R
a
b
c
d

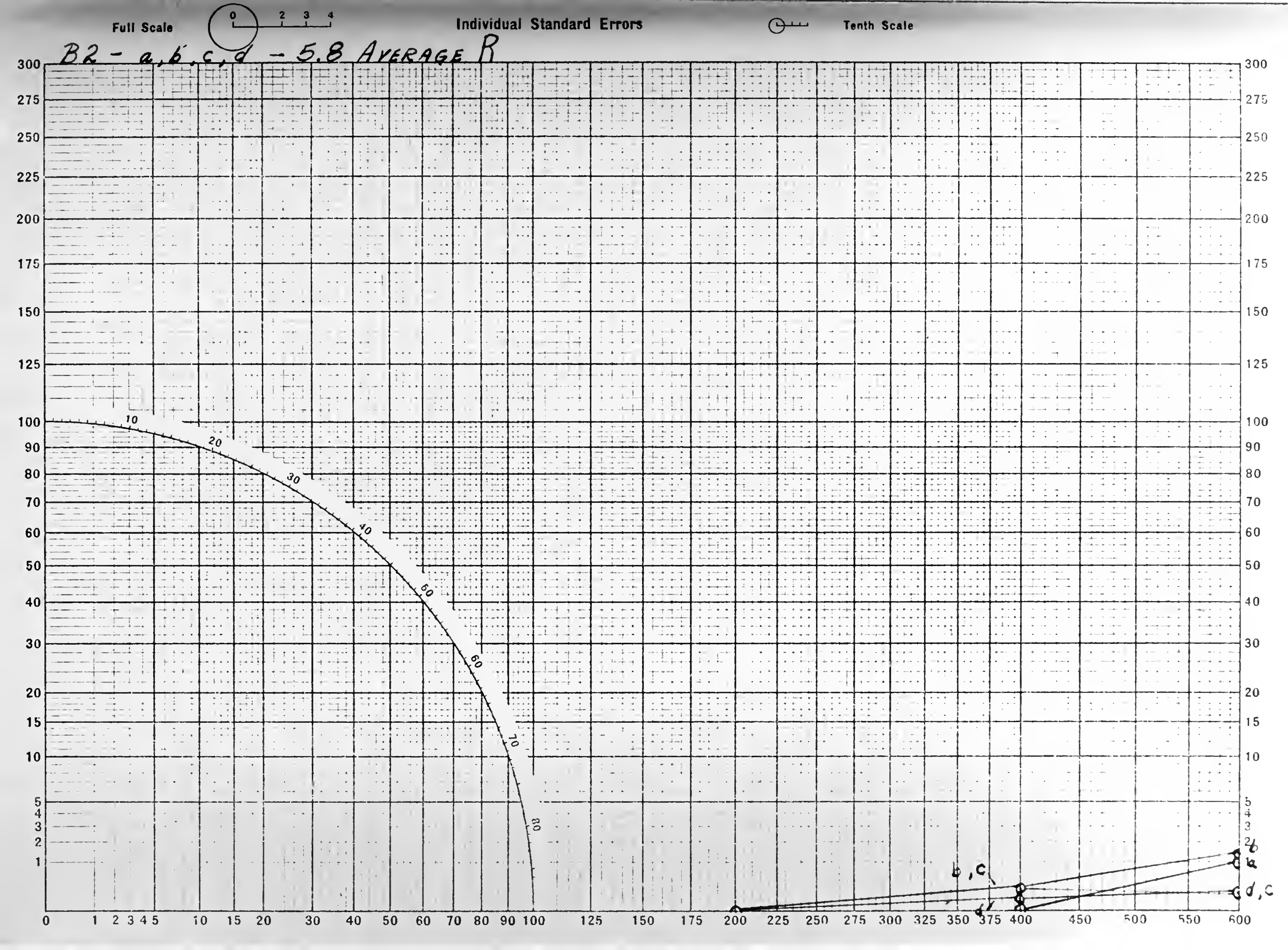
Full Scale

Individual Standard Errors

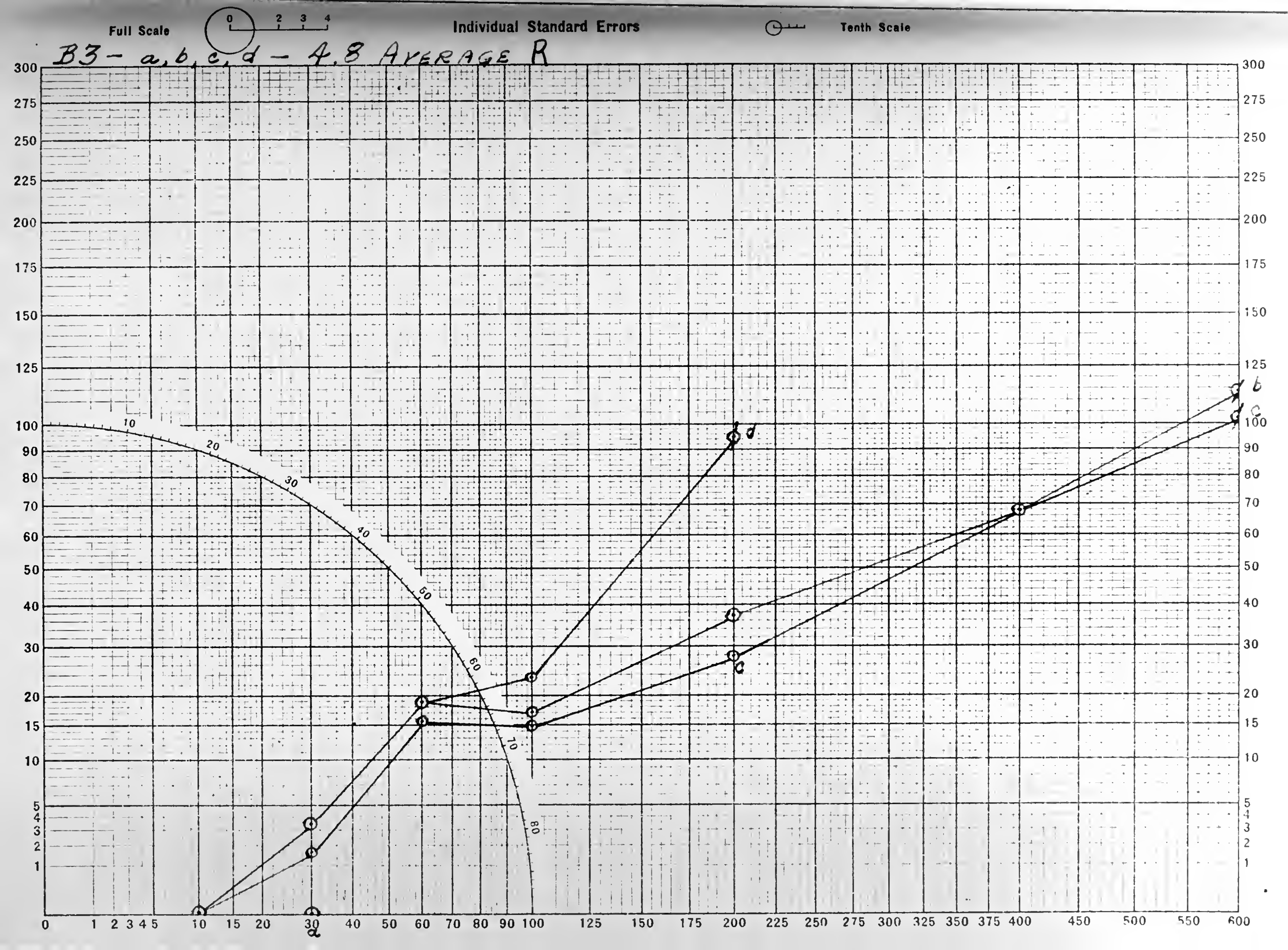
Tenth Scale

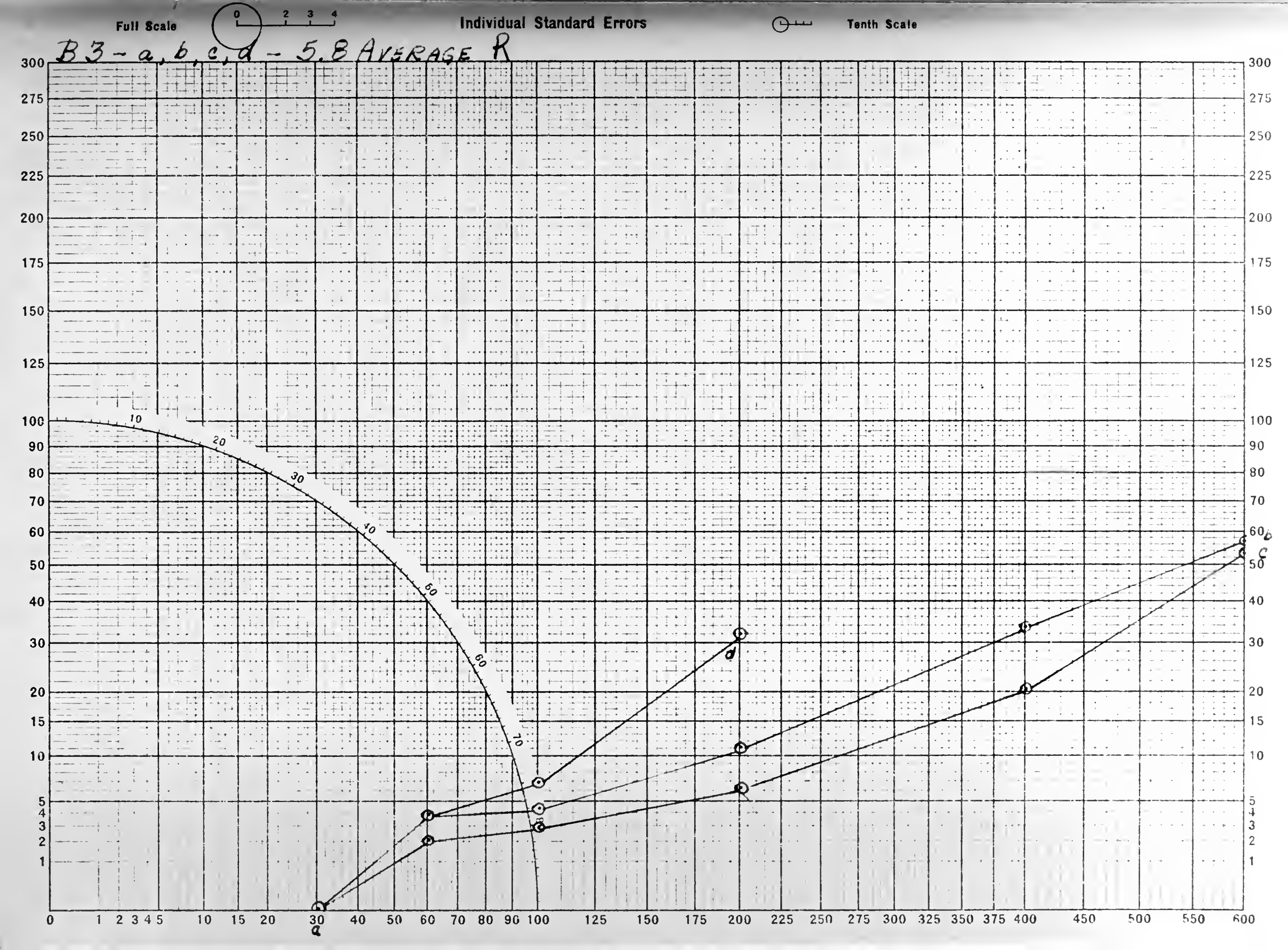
B2 - a, b, c, d - 4.8 AVERAGE R



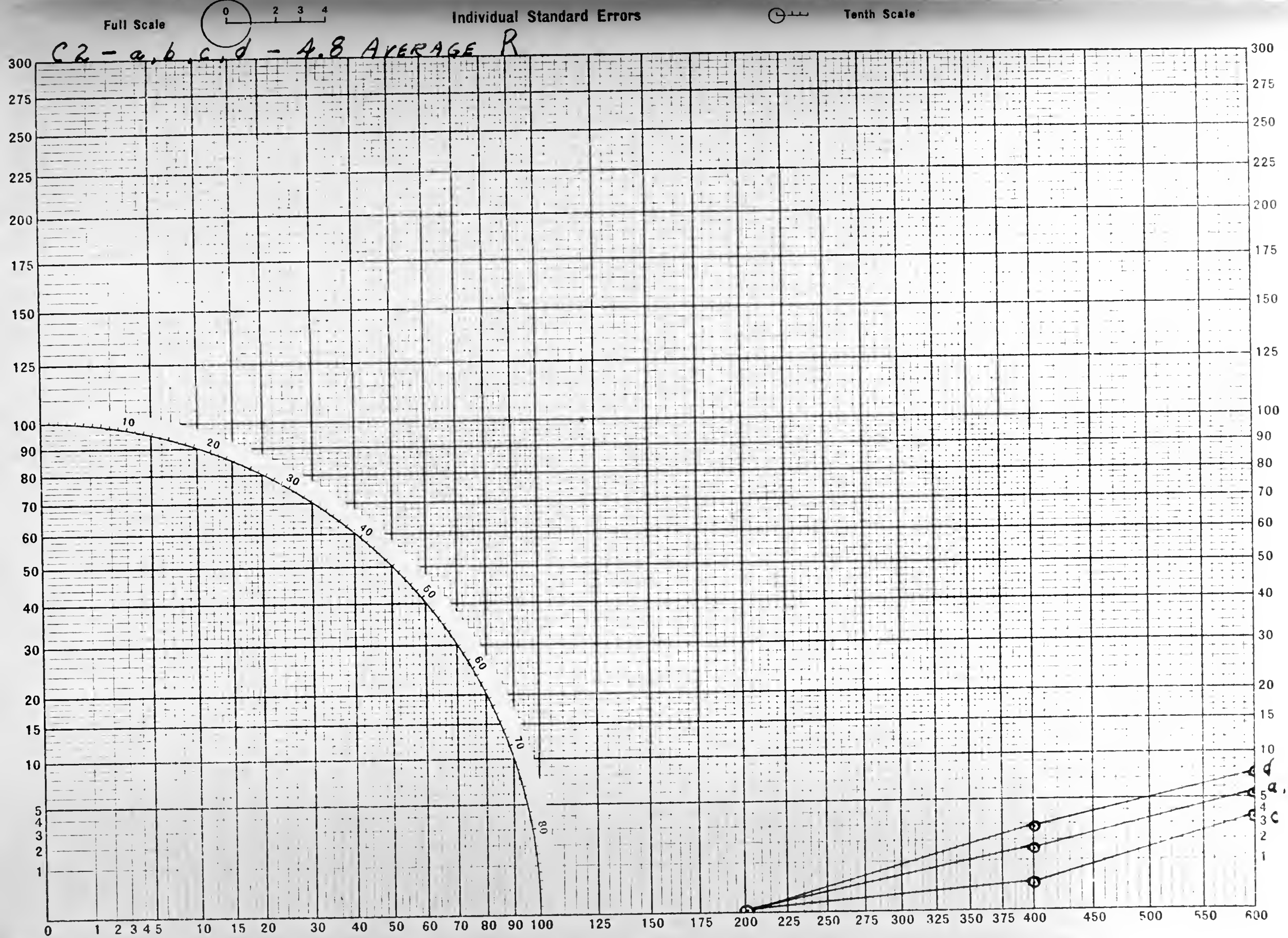


Full Scale
Individual Standard Errors
Tenth Scale
B2 - a, b, c, d - 5.8 AVERAGE R
b, c
d
d, c


Full Scale
Individual Standard Errors
Tenth Scale
B3 - a, b, c, d - 4.8 AVERAGE R
a
b
c
d



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B3 - a, b, c, d - 5.8 AVERAGE R
a
b
c
d



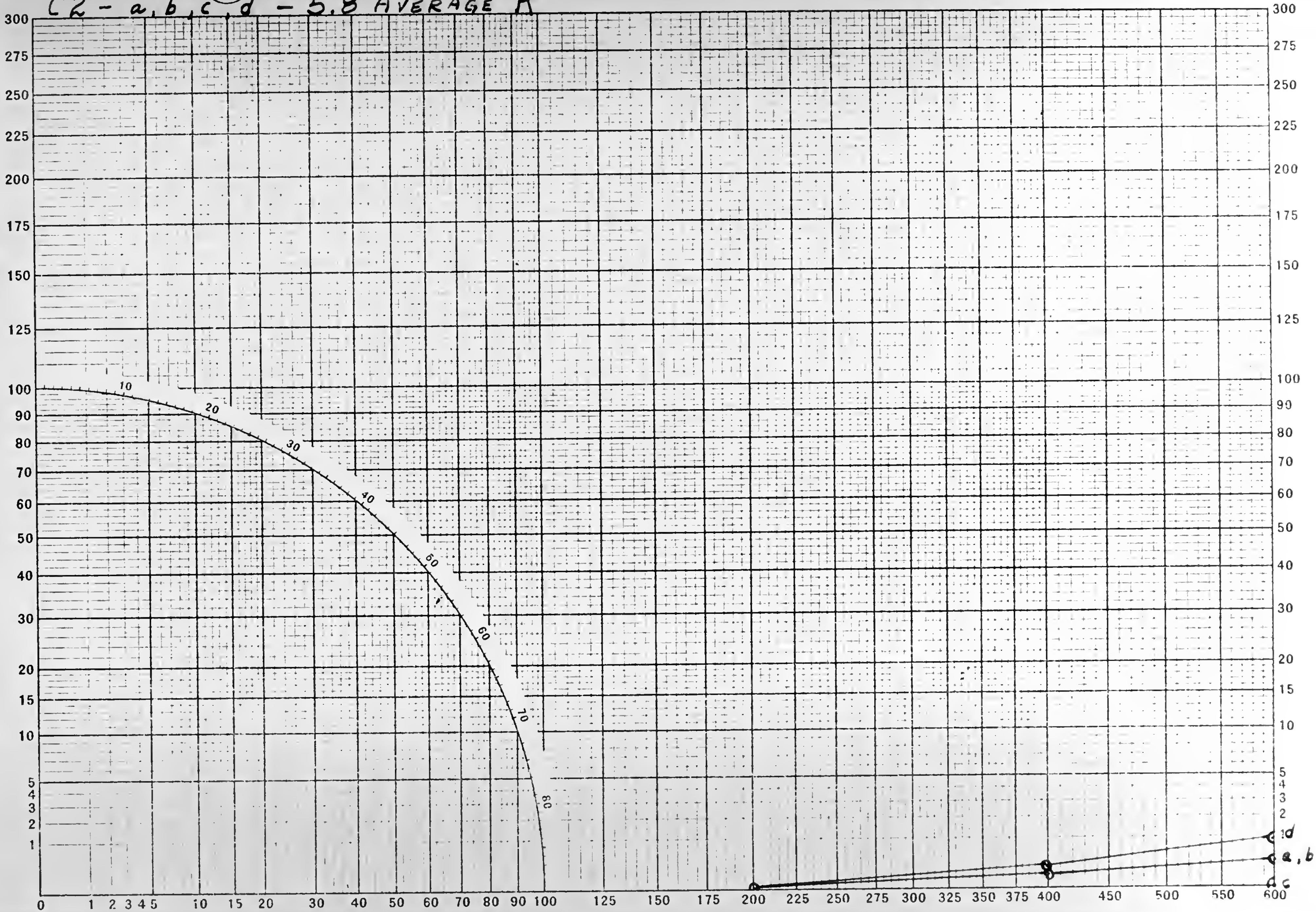
Full Scale
Individual Standard Errors
Tenth Scale
C2 - a, b, c, d - 4.8 AVERAGE R

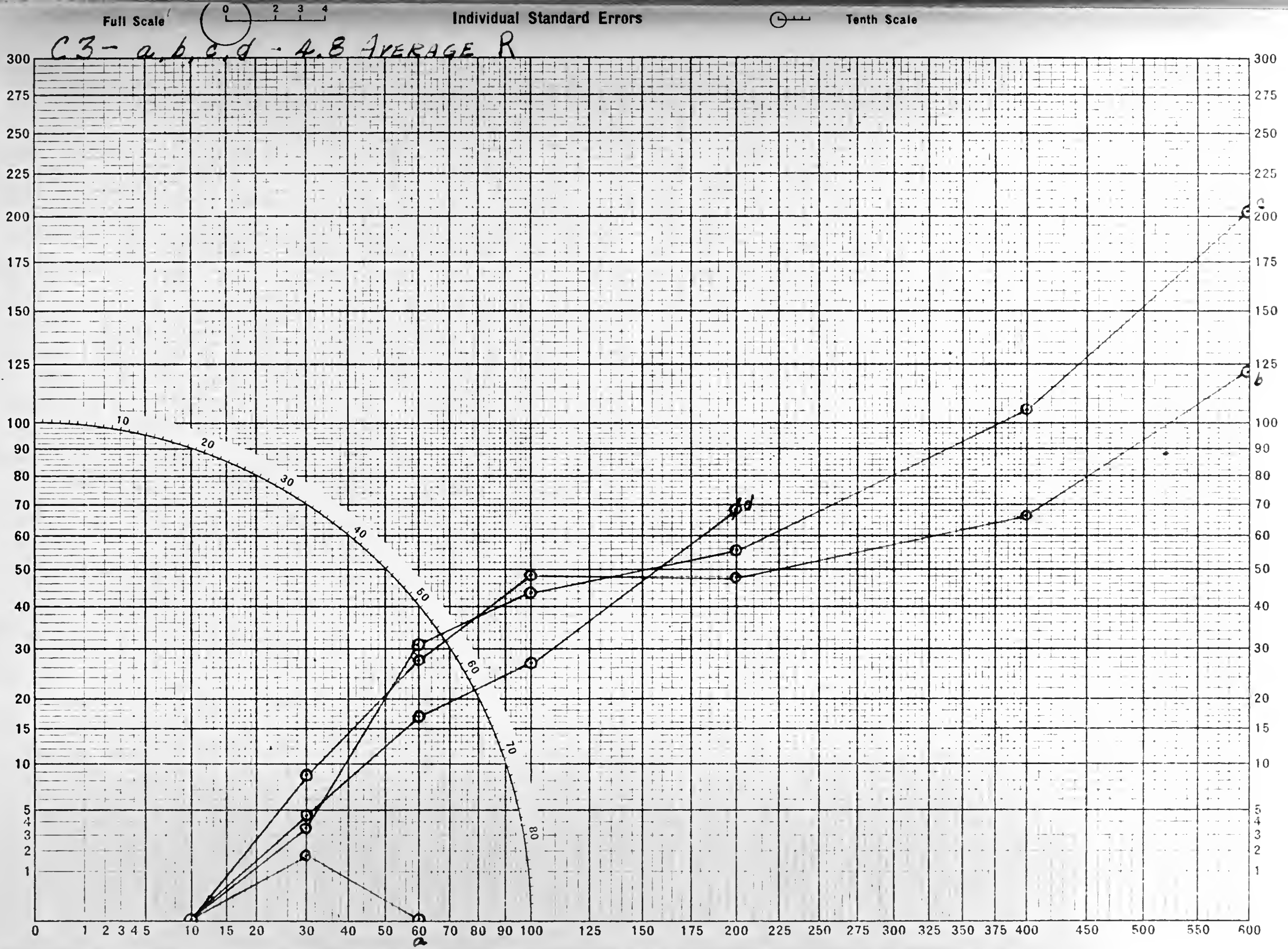
Full Scale

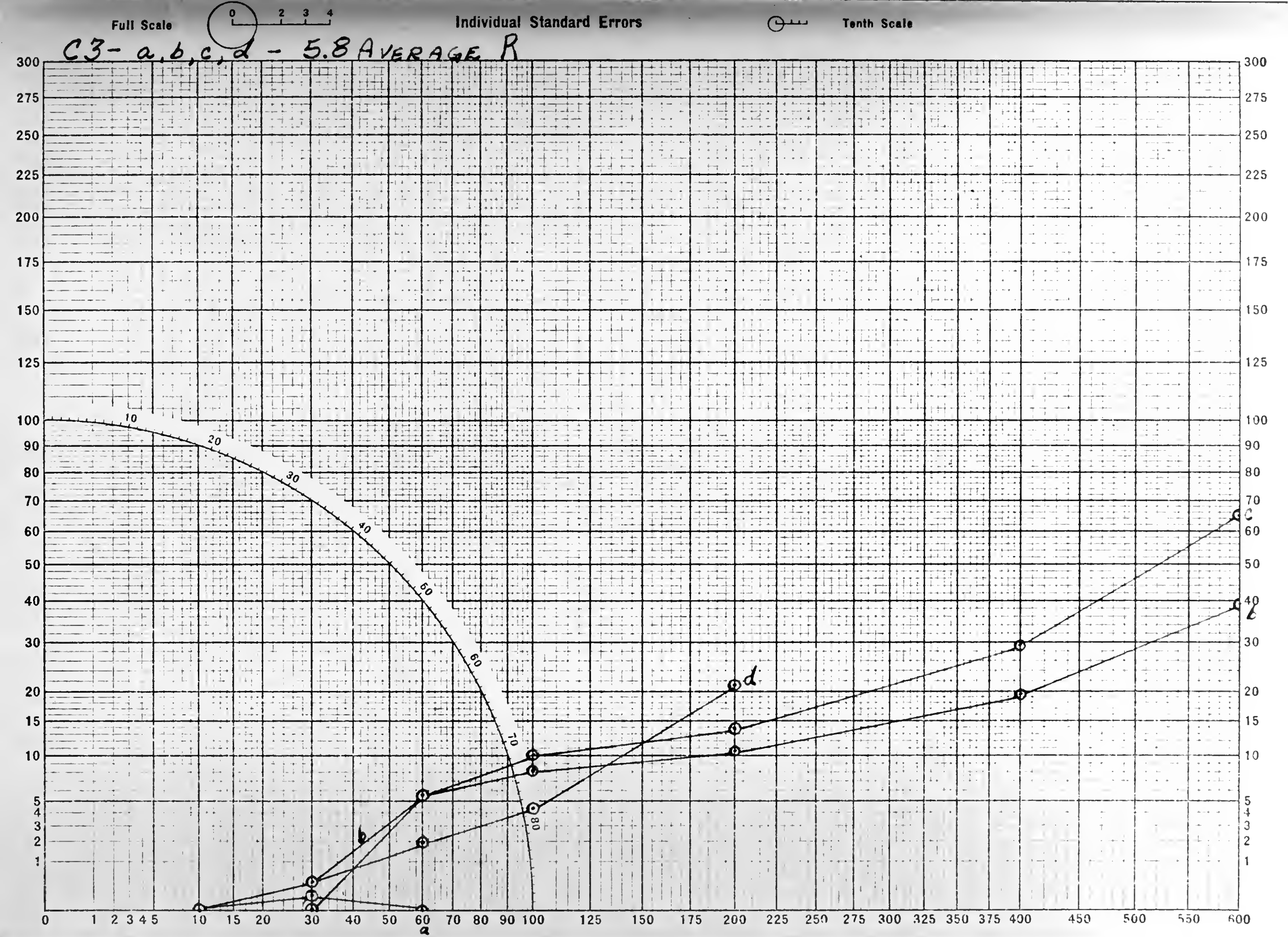
Individual Standard Errors

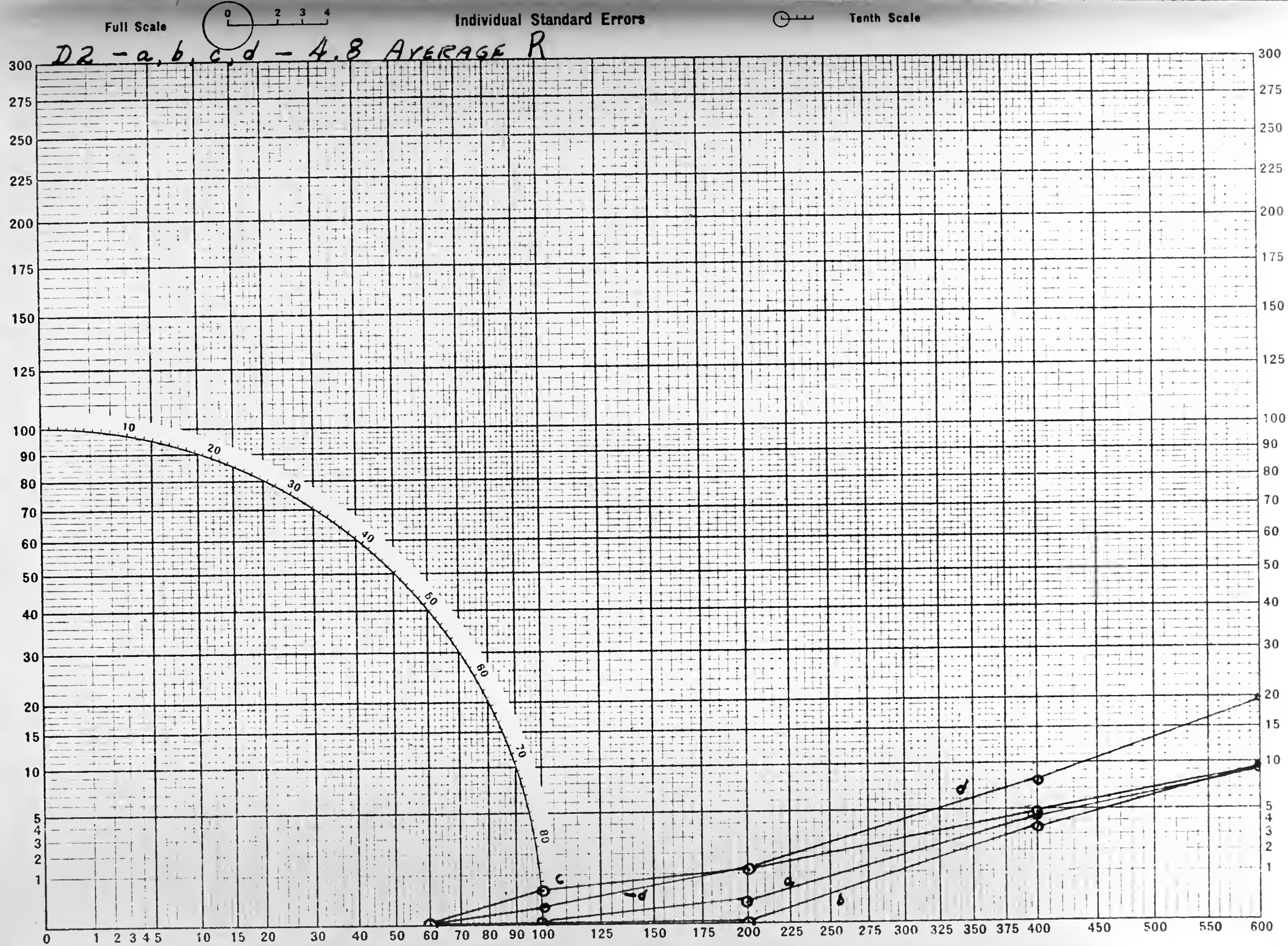
Tenth Scale

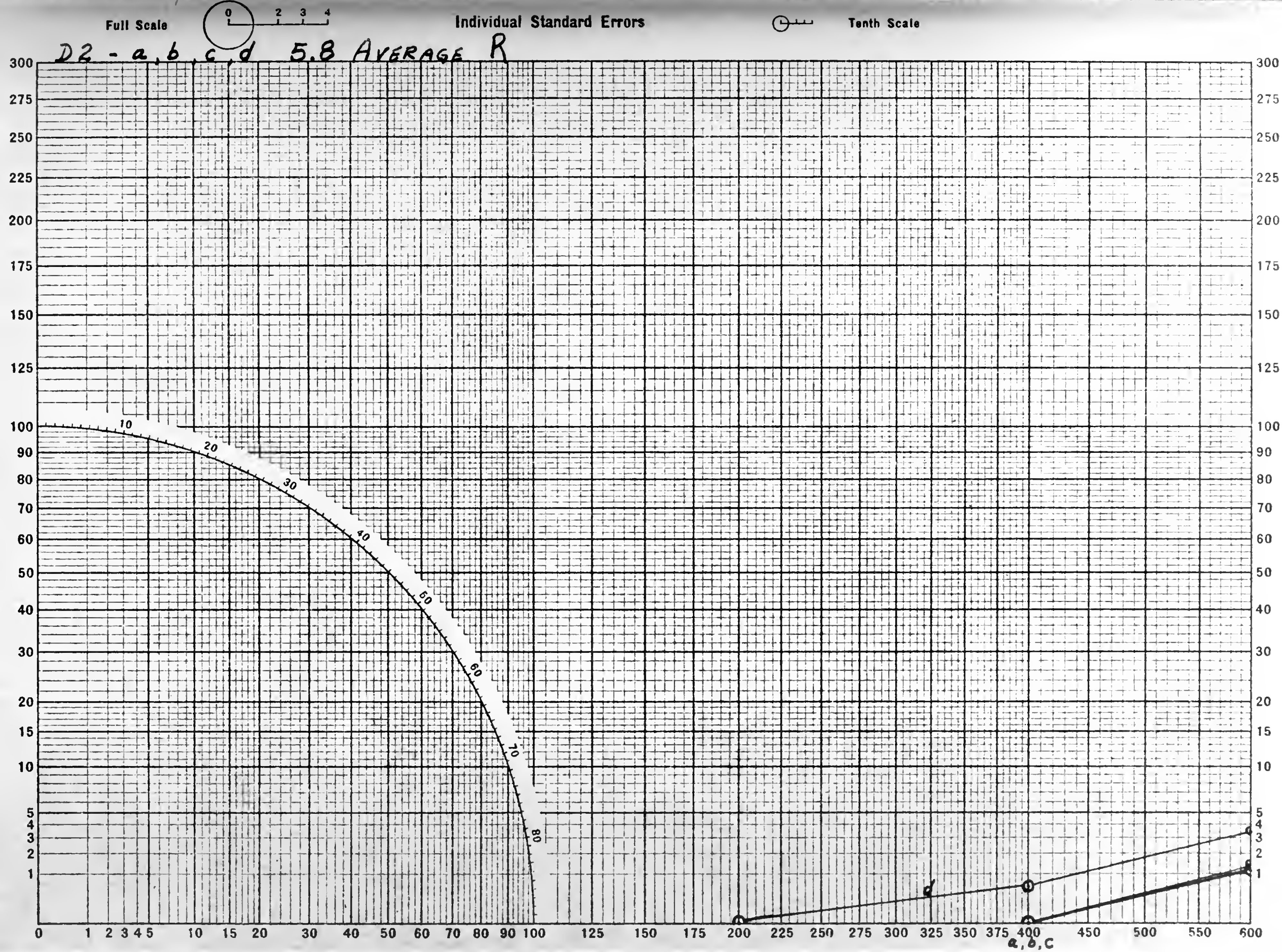
C2 - a, b, c, d - 5.8 AVERAGE R

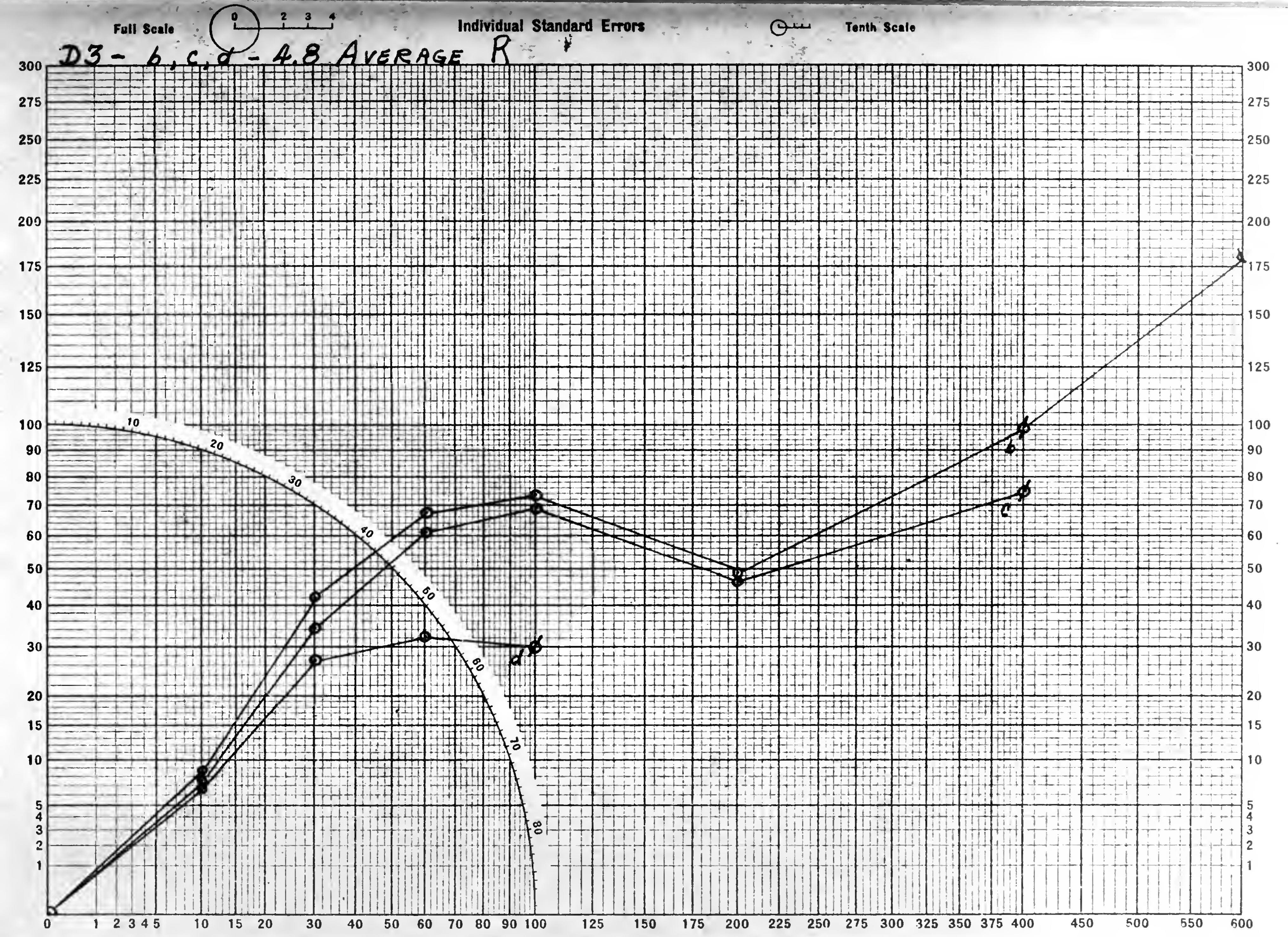



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3- a, b, c, d - 4.8 Average R
a
b
c
d

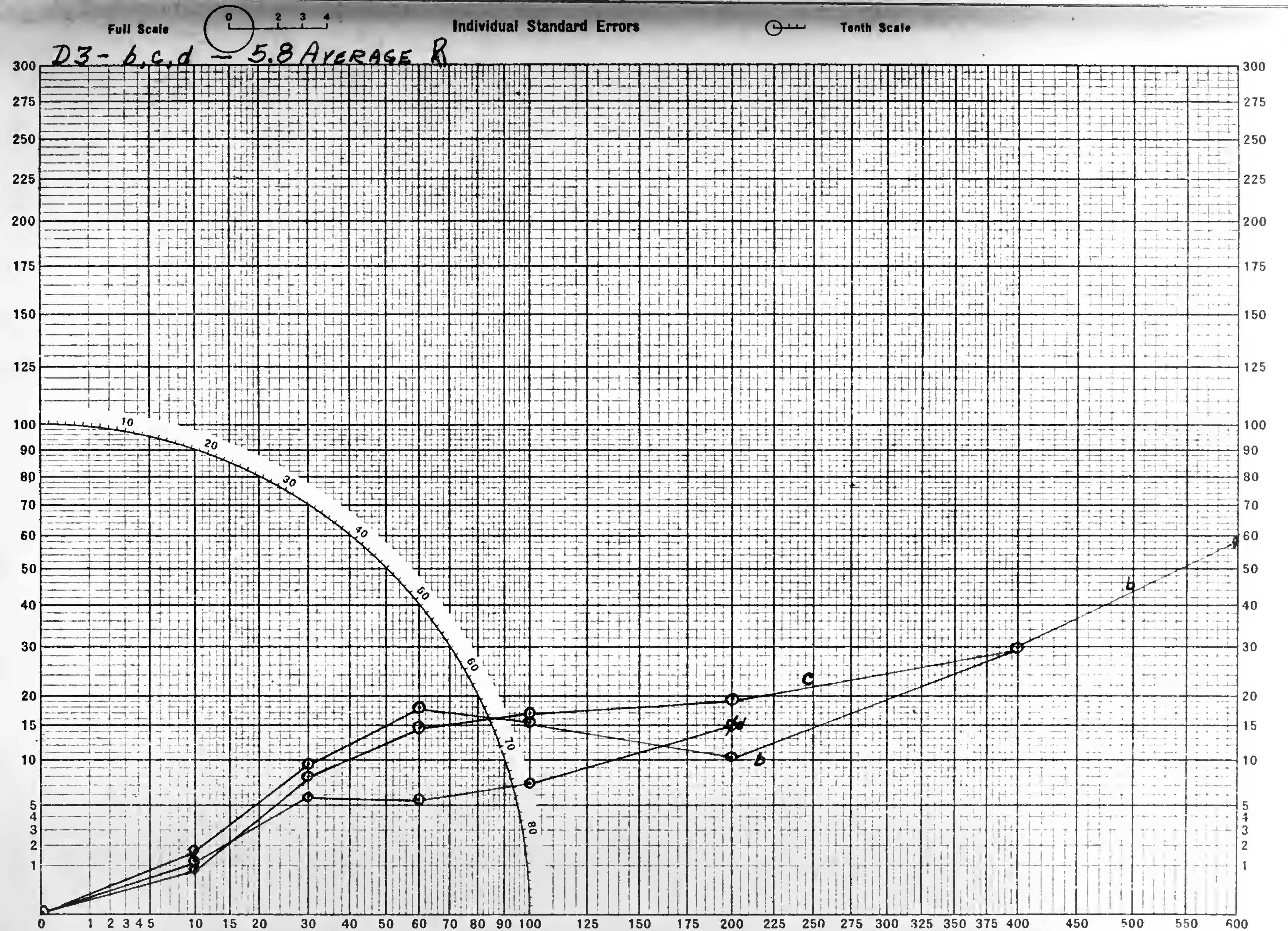

Full Scale
Individual Standard Errors
Tenth Scale
C3- a, b, c, d - 5.8 AVERAGE R
a
b
c
d


Full Scale
Individual Standard Errors
Tenth Scale
D2 - a, b, c, d - 4.8 AVERAGE R
a
b
c
d
d


Full Scale
Individual Standard Errors
Tenth Scale
D2 - a, b, c, d 5.8 AVERAGE R
d
a, b, C

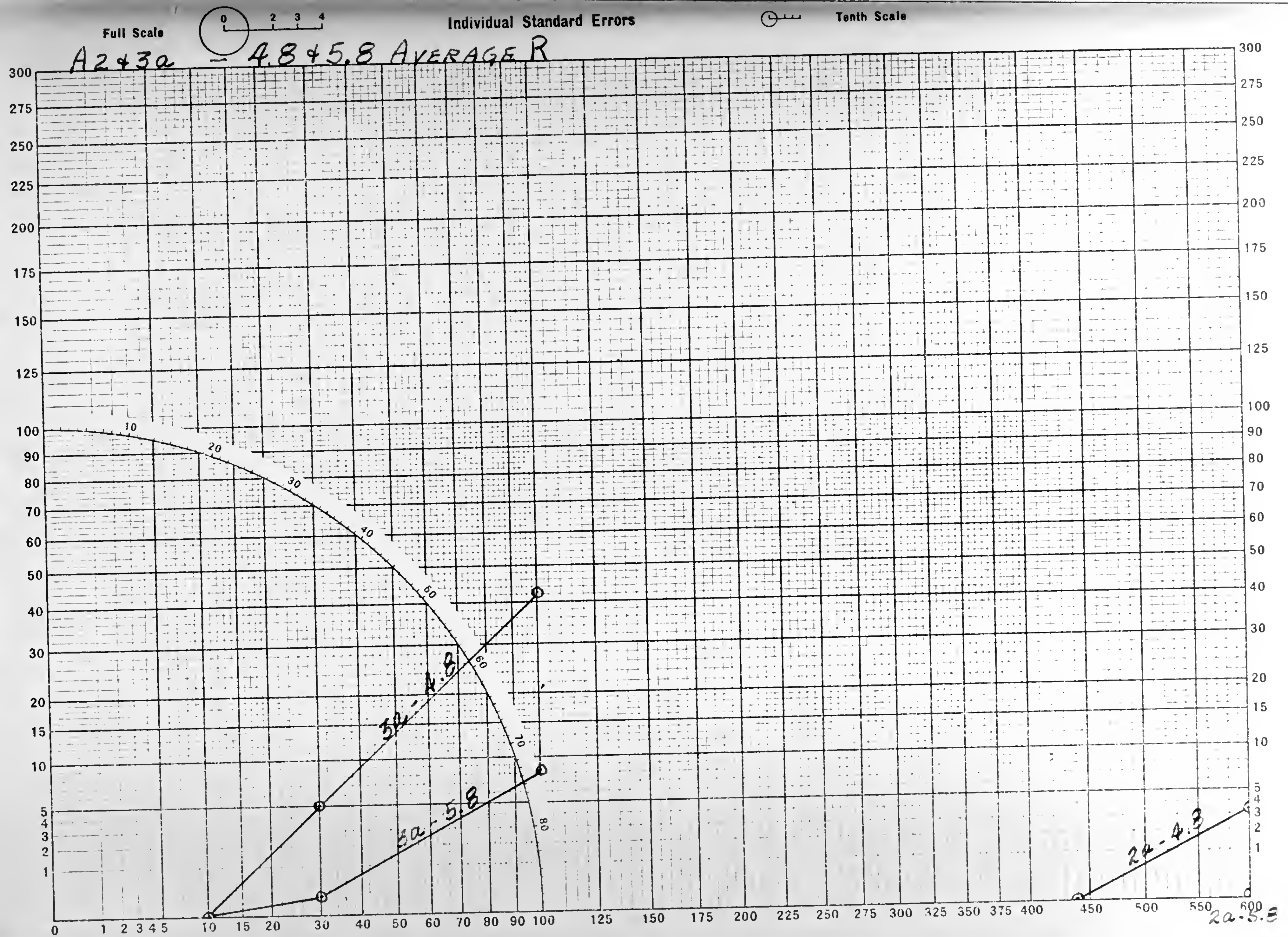


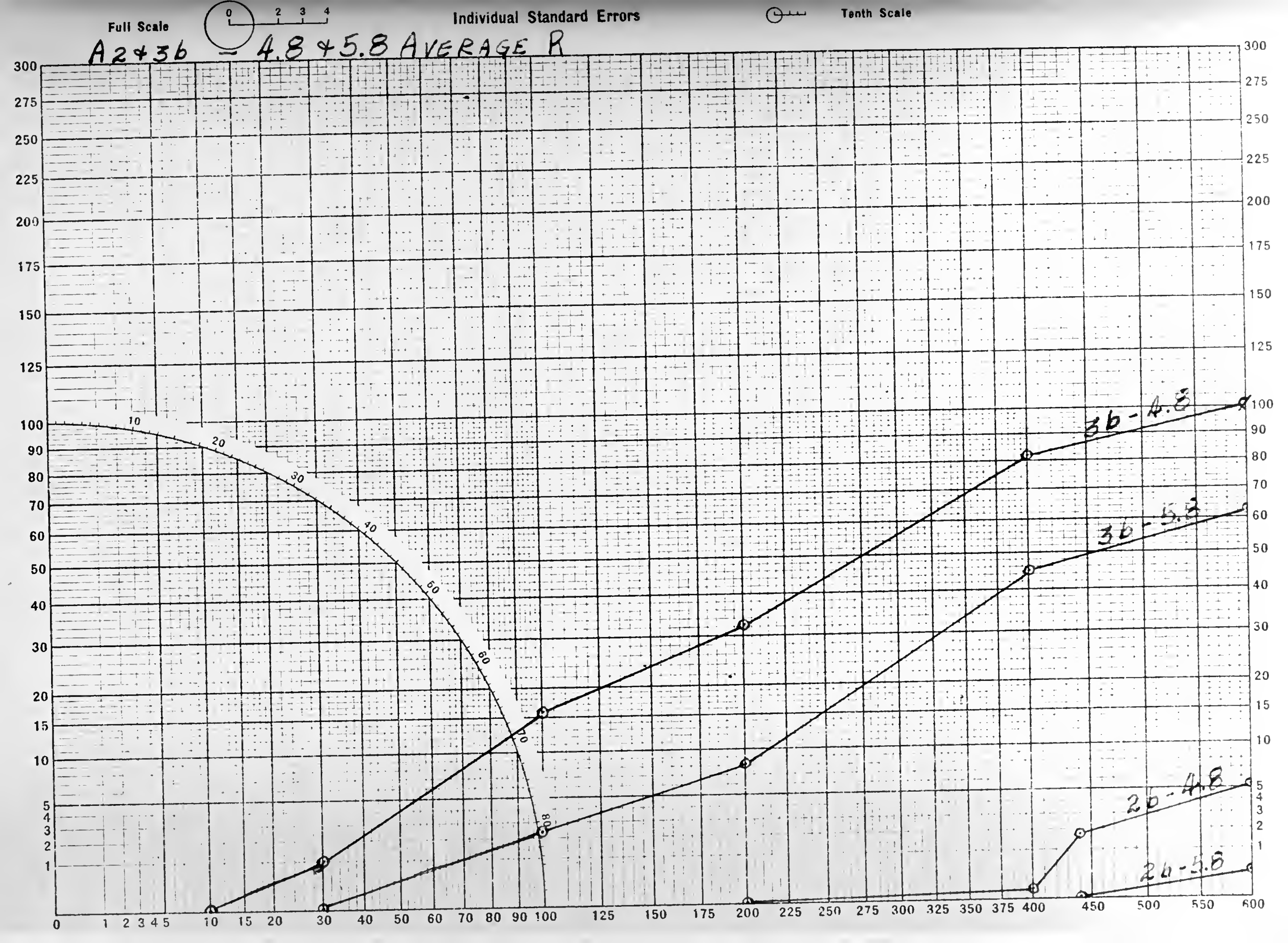
Full Scale
Individual Standard Errors
Tenth Scale
D3 - b, c, d - 4.8 AVERAGE R
b
c
d



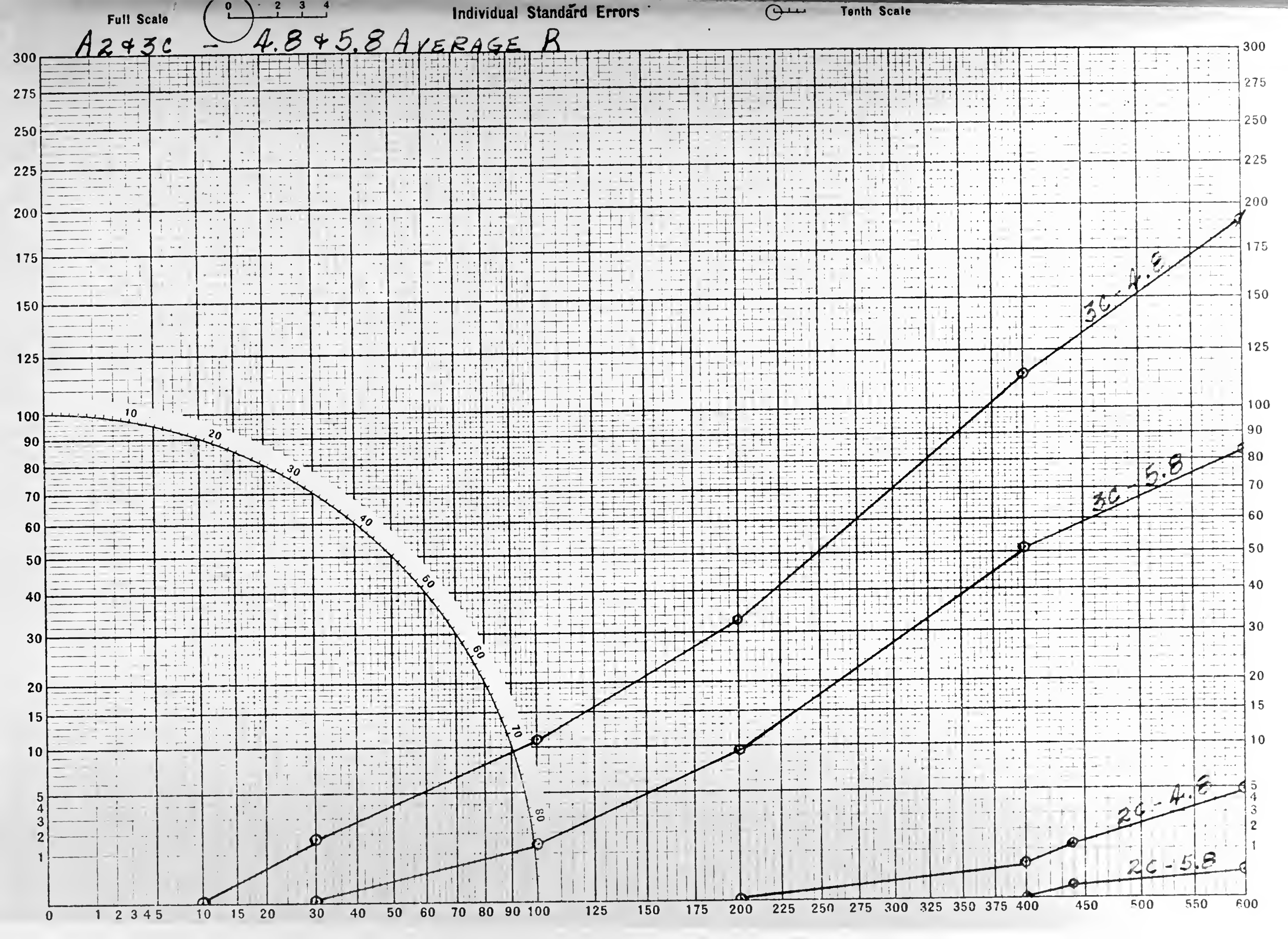
Full Scale
Individual Standard Errors
Tenth Scale
D3 - b,c,d - 5.8 AVERAGE R
c
b
d

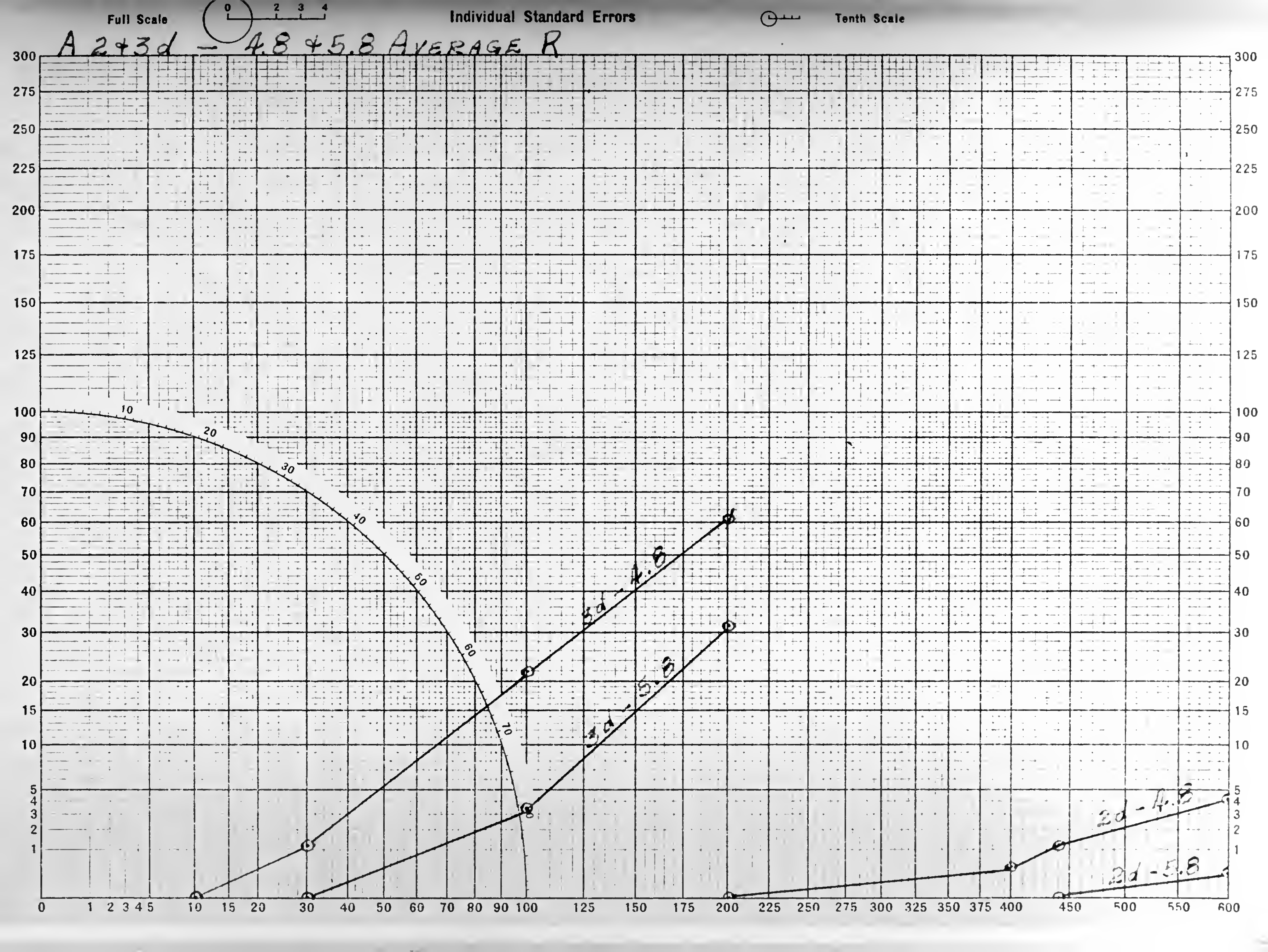
AVERAGE RESISTANCE, COMPARING OPERATING CATHODE TEMPERATURE EFFECTS

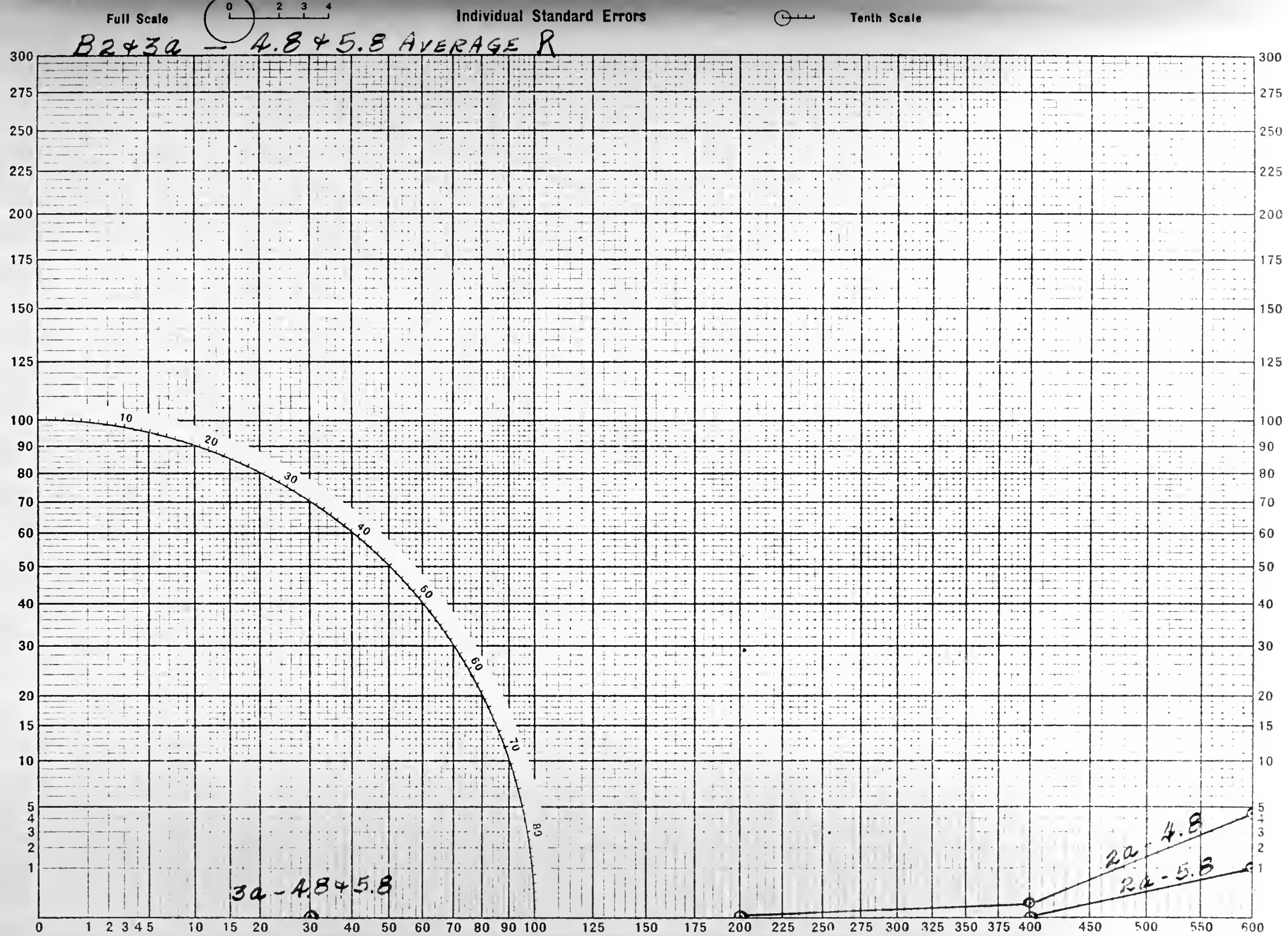

Full Scale
Individual Standard Errors
Tenth Scale
A2 + 3a - 4.8 + 5.8 Average R
3a - 4.8
2a - 5.8
2a - 4.8
2a - 5.8

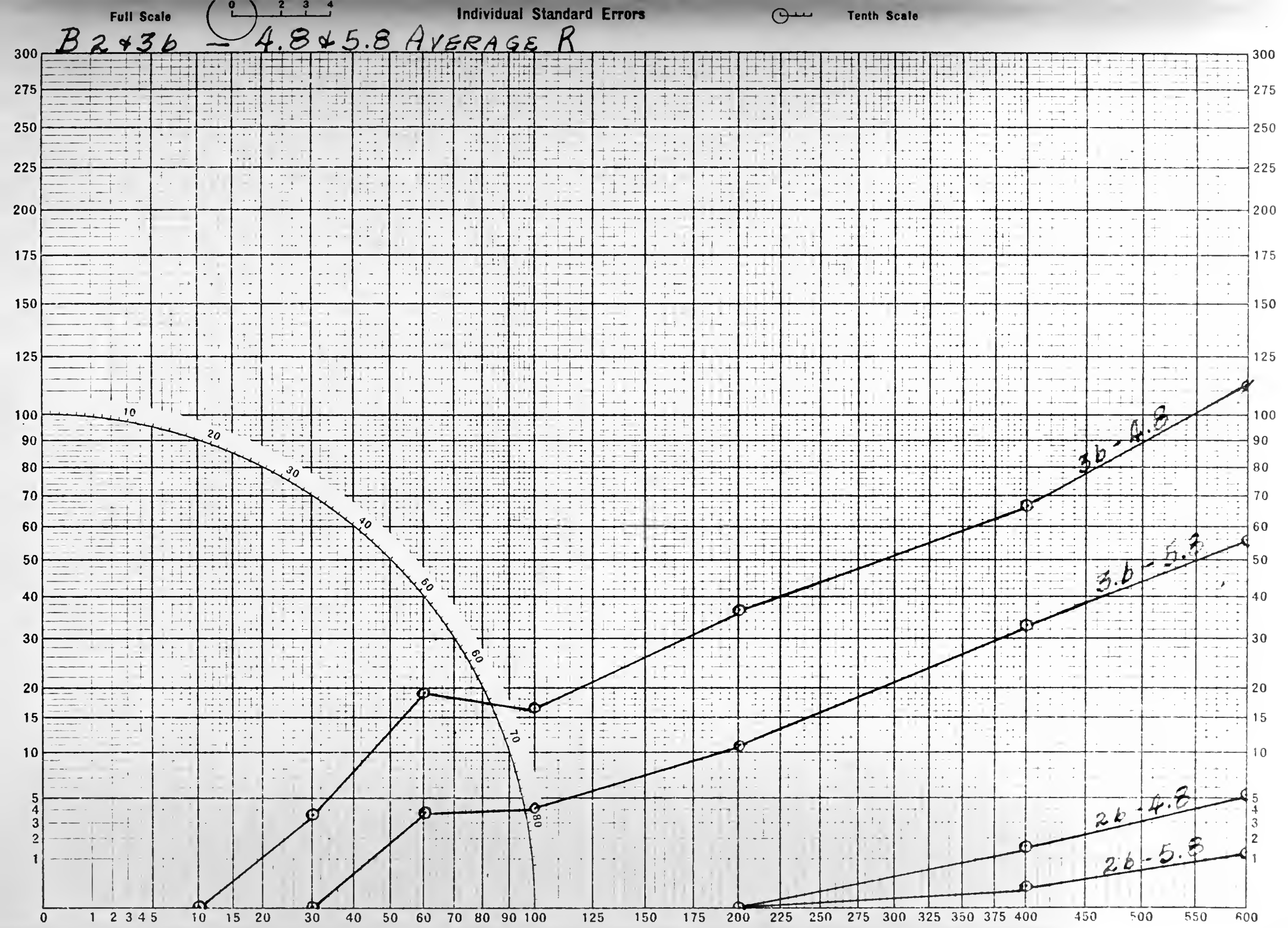


Full Scale
Individual Standard Errors
Tenth Scale
A2 + 3b — 4.8 + 5.8 AVERAGE R
3b - 4.8
3b - 5.8
2b - 4.8
2b - 5.8

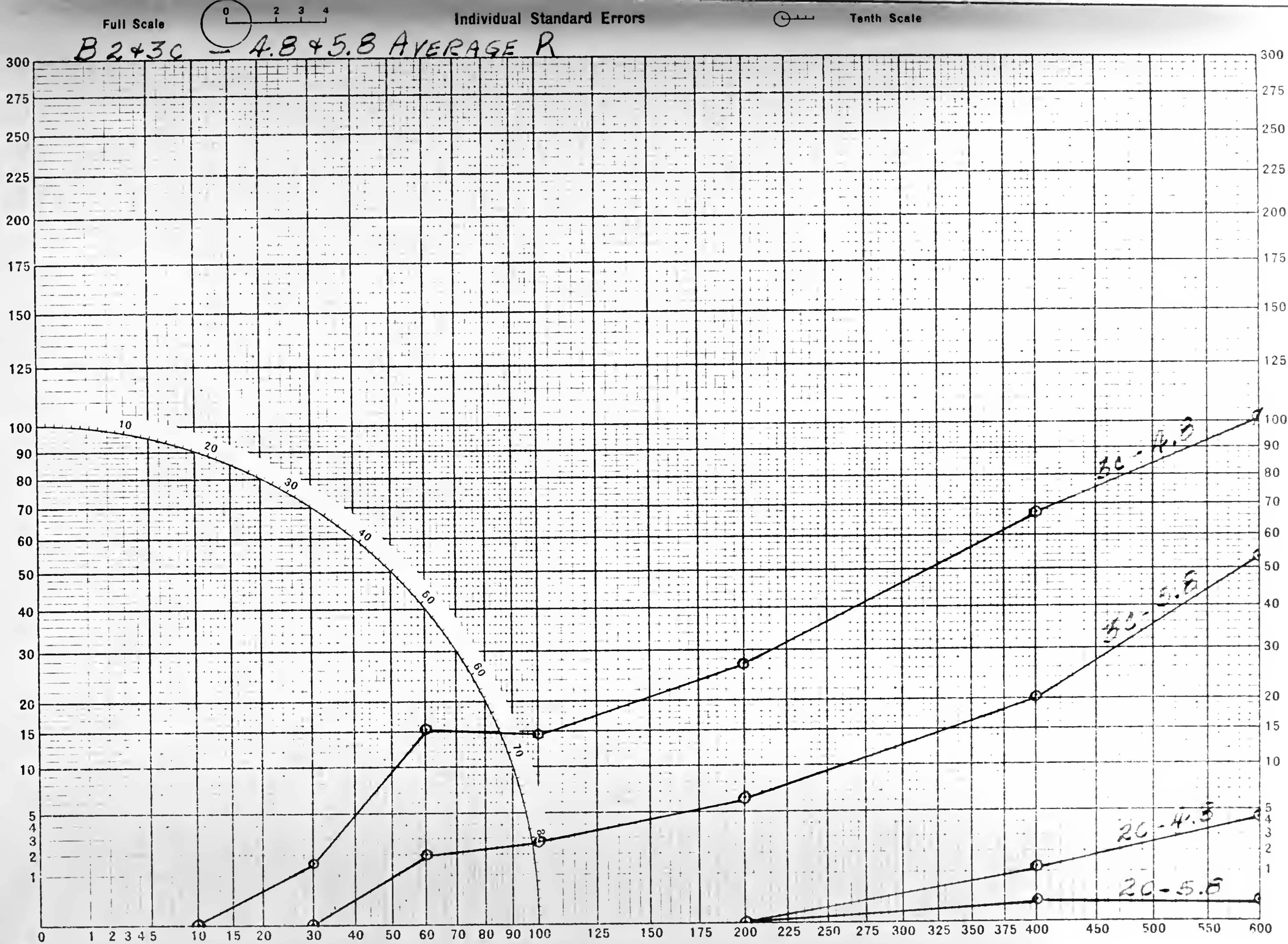

Full Scale
Individual Standard Errors
Tenth Scale
A2 & 3C - 4.8 & 5.8 AVERAGE B
3C - 4.8
3C - 5.8
2C - 4.8
2C - 5.8

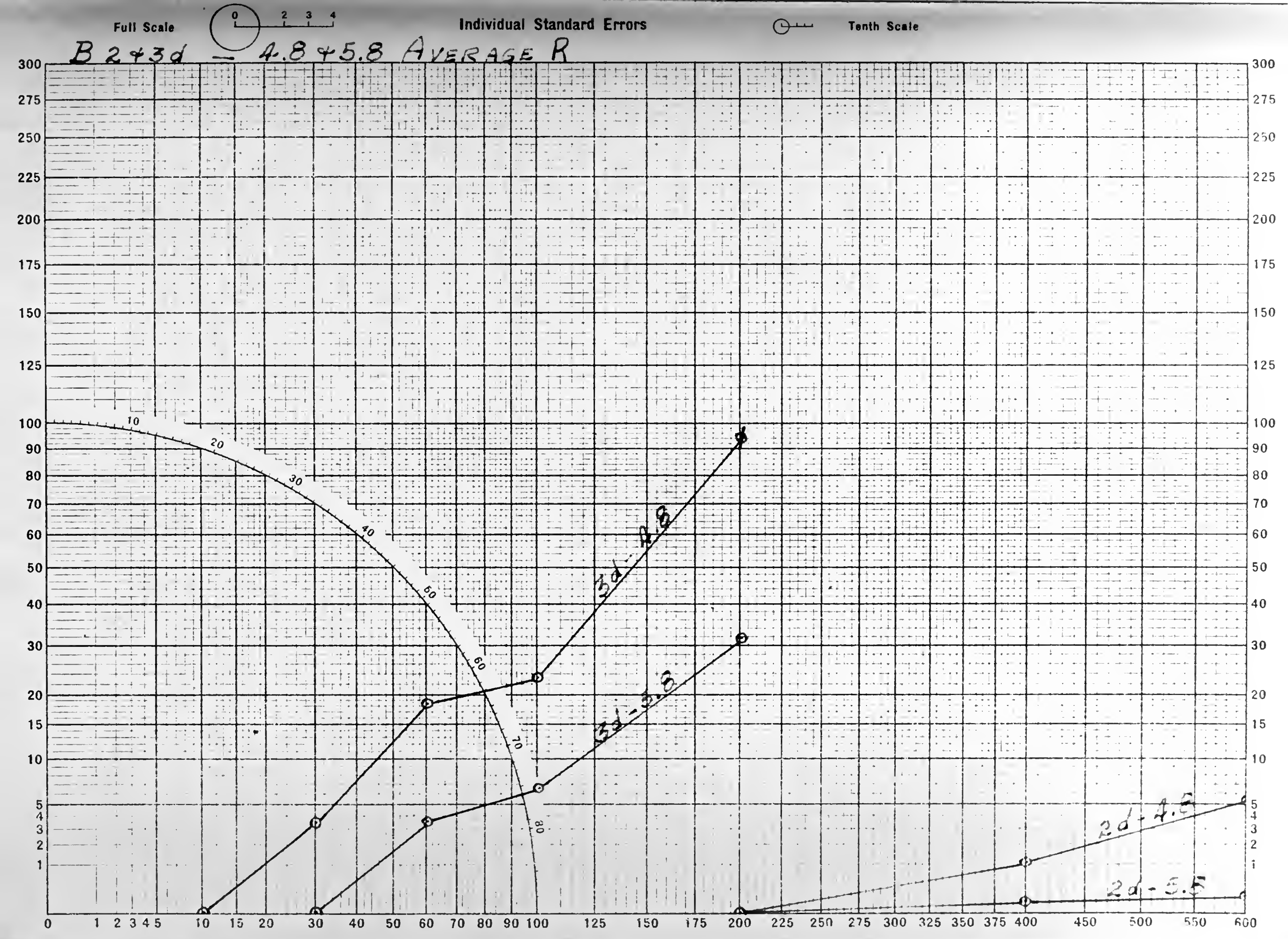

Full Scale
Individual Standard Errors
Tenth Scale
A 2+3d — 4.8+5.8 Average R
3d - 4.8
3d - 5.8
2d - 4.8
2d - 5.8


Full Scale
Individual Standard Errors
Tenth Scale
B2 + 3a — 4.8 + 5.8 AVERAGE R
3a - 4.8 + 5.8
2a - 4.8
2a - 5.8



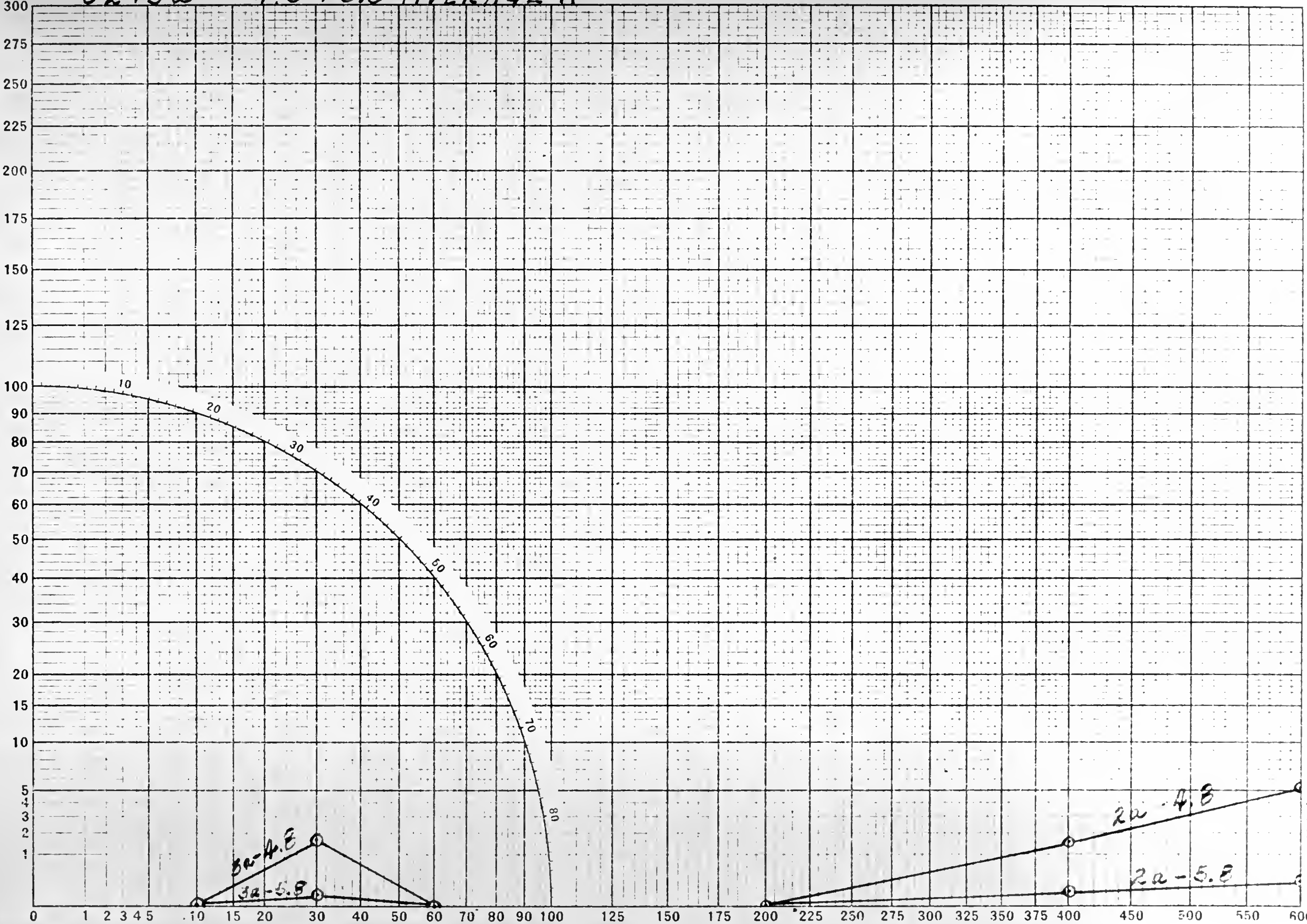
Full Scale
Individual Standard Errors
Tenth Scale
B 2 & 3b — 4.8 & 5.8 AVERAGE R
3b - 4.8
3.b - 5.8
2b - 4.8
2b - 5.8

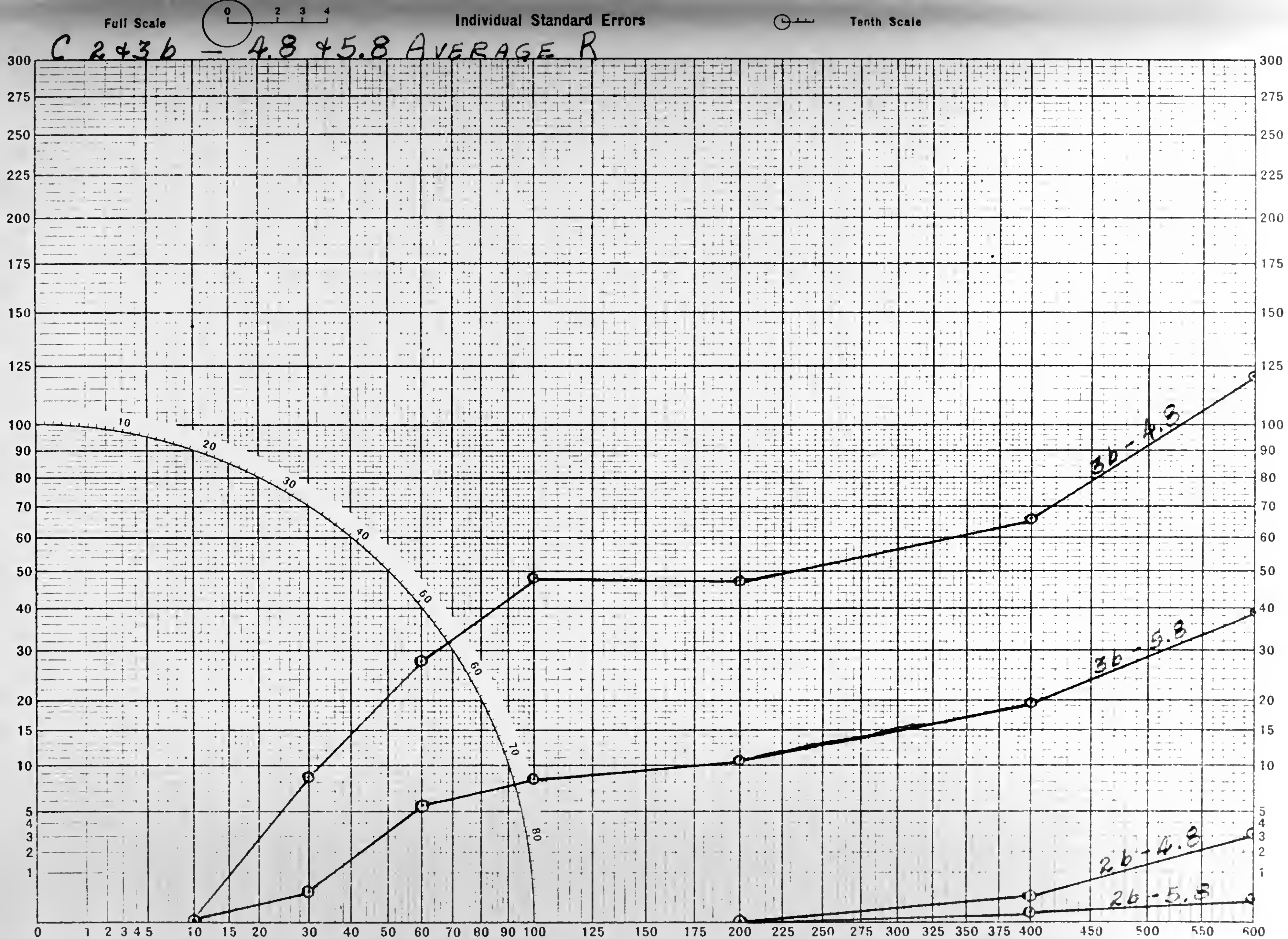

Full Scale
Individual Standard Errors
Tenth Scale
B 2+3C — 4.8 + 5.8 AVERAGE R
3C - 4.8
3C - 5.8
2C - 4.8
2C - 5.8


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B 2+3d — 4.8+5.8 AVERAGE R
3d - 4.8
3d - 5.8
2d - 4.8
2d - 5.5
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
10 20 30 40 50 60 70 80

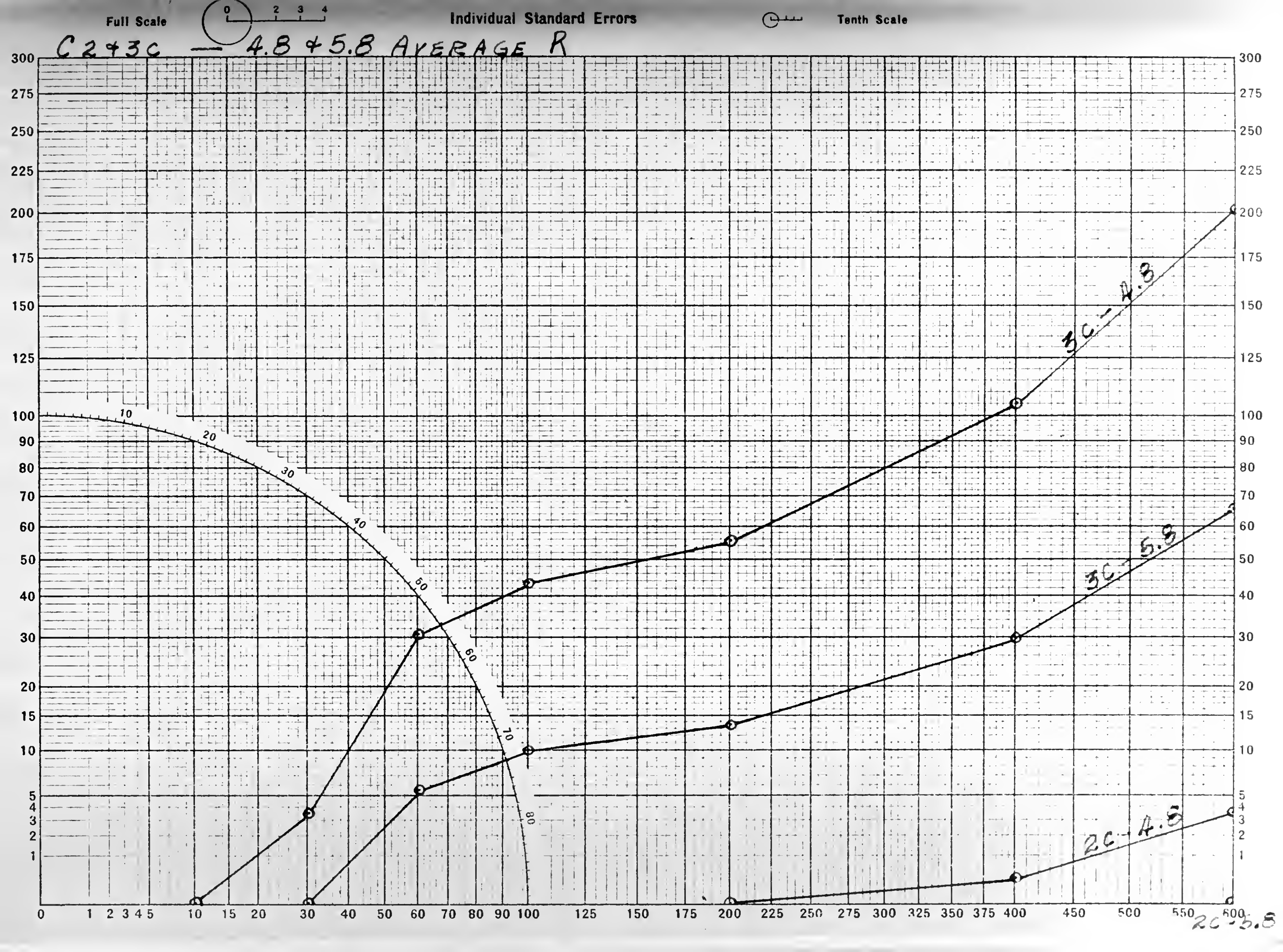
Full Scale   0 1 2 3 4   **Individual Standard Errors**   Tenth Scale

C2 + 3a – 4.8 + 5.8 AVERAGE R

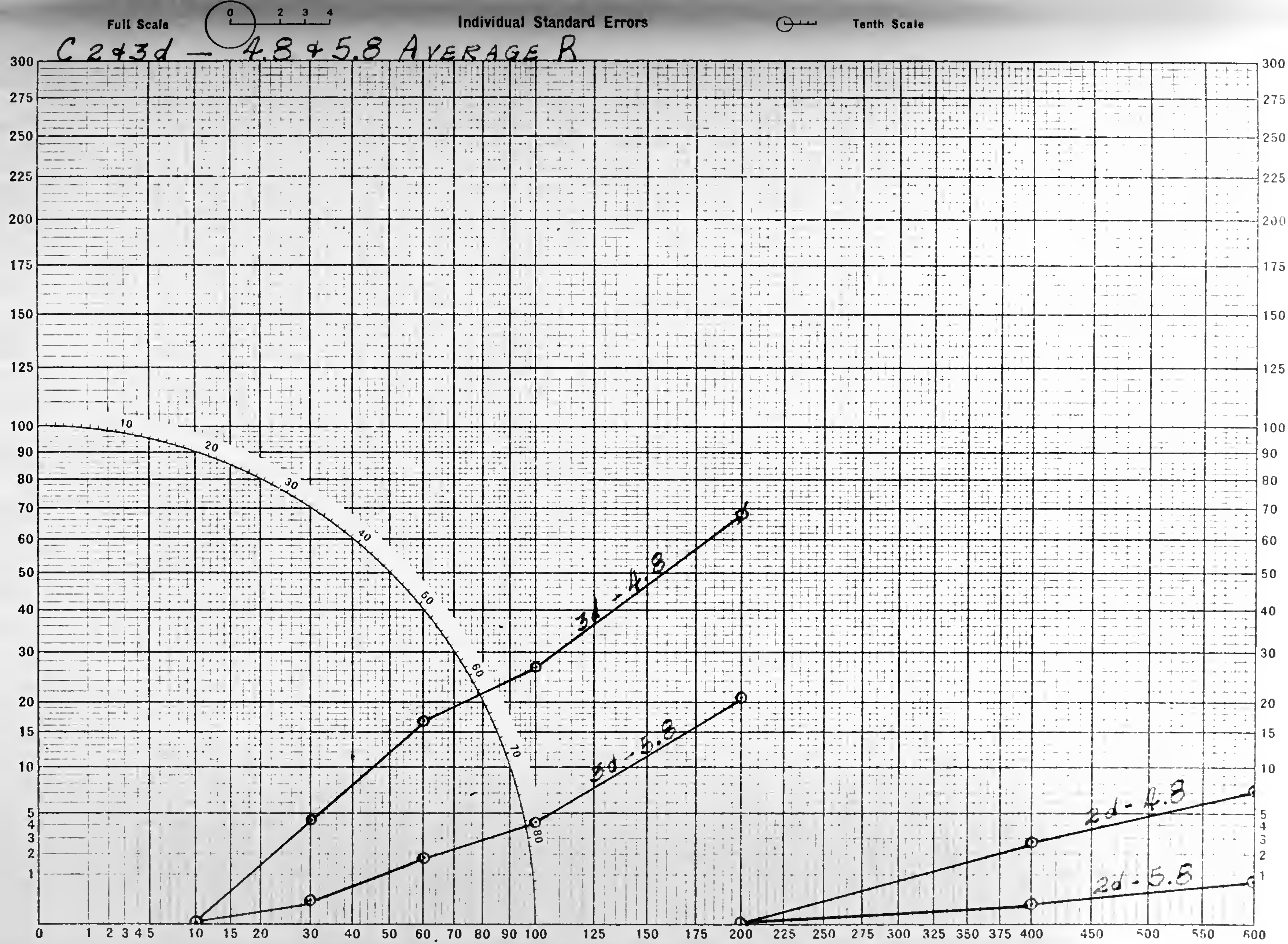


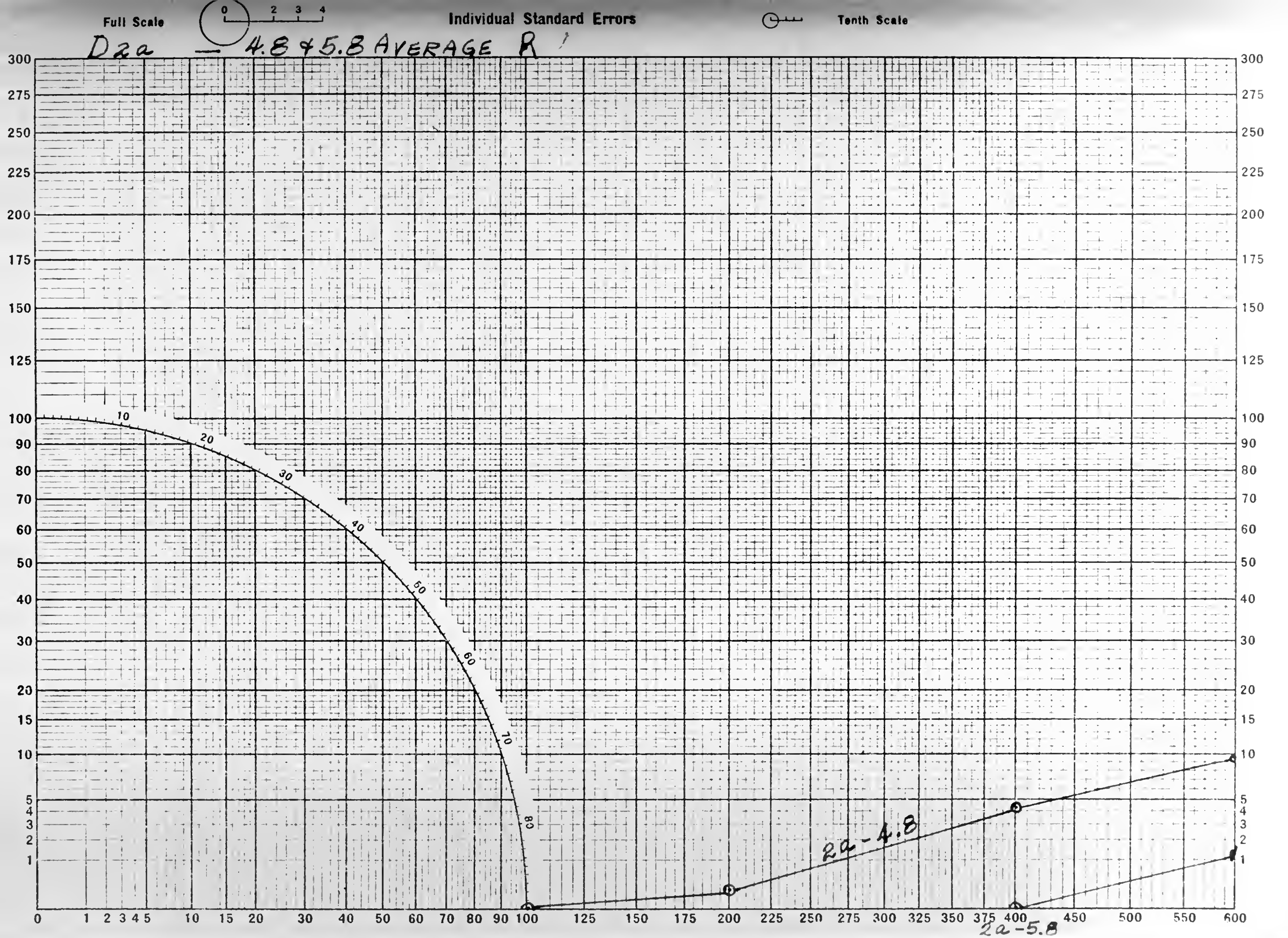


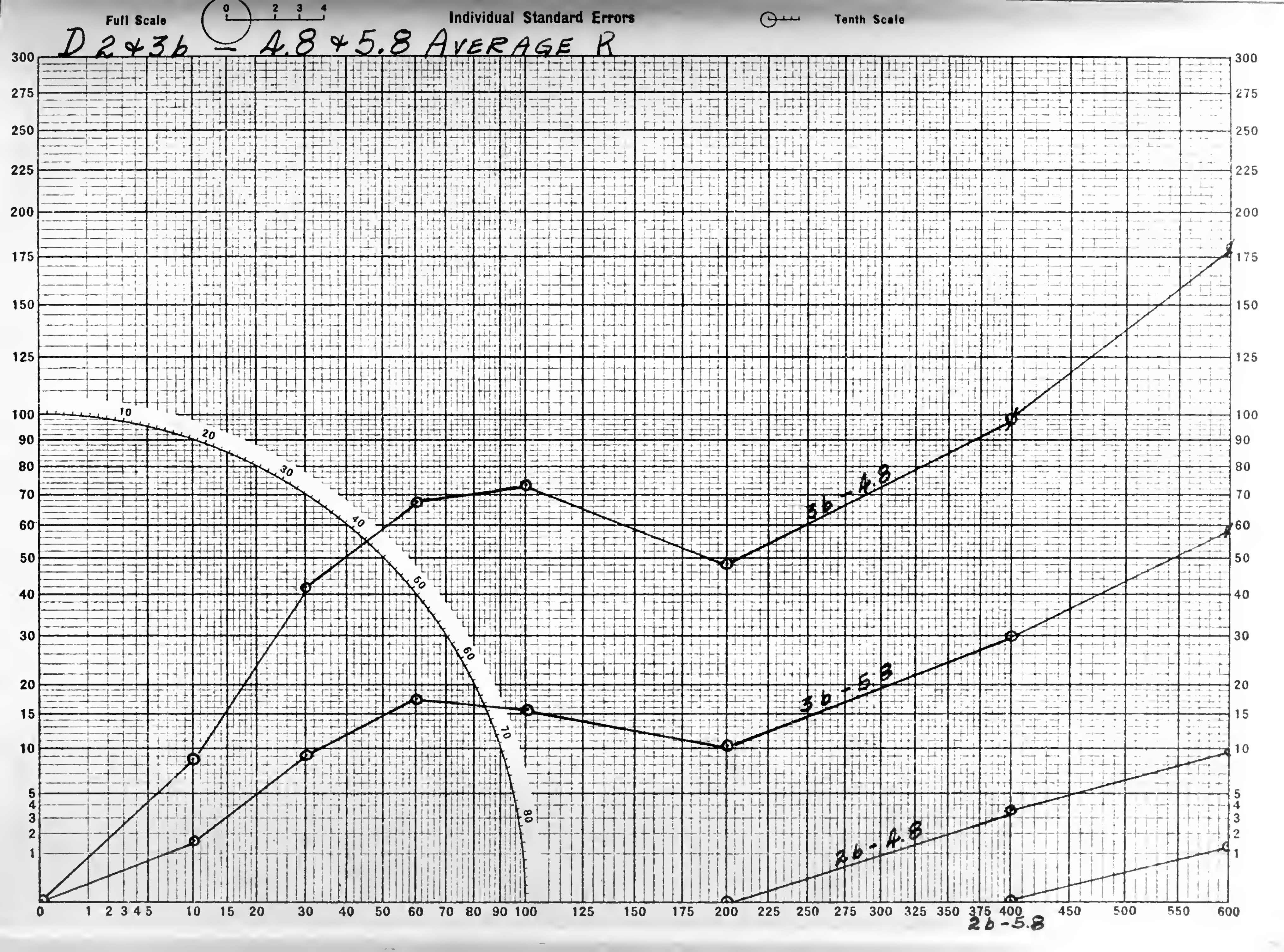
Full Scale
Individual Standard Errors
Tenth Scale
C 2+3b — 4.8 + 5.8 AVERAGE R
3b - 4.8
3b - 5.8
2b - 4.8
2b - 5.8



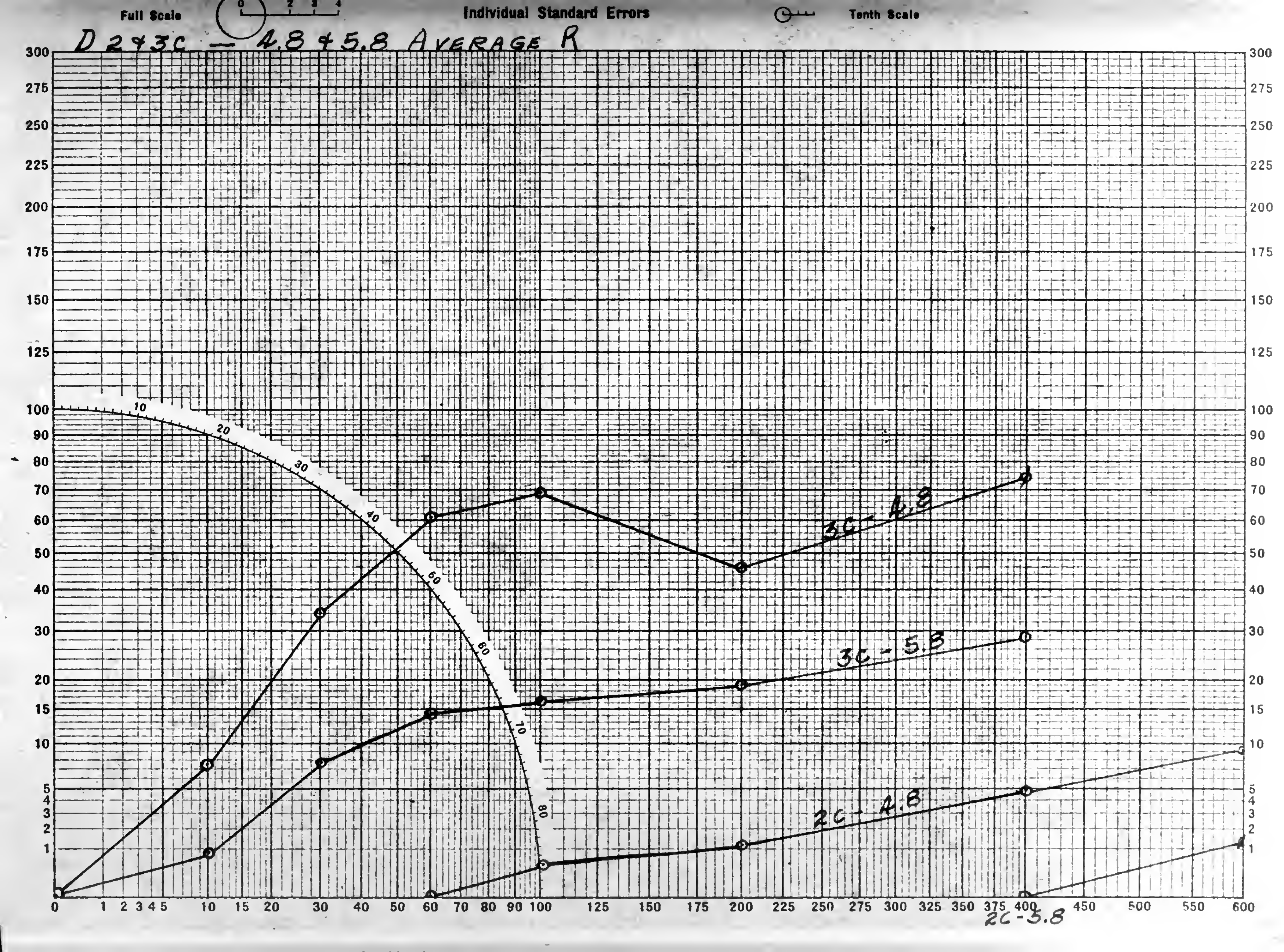
Full Scale
Individual Standard Errors
Tenth Scale
C2+3C — 4.8 + 5.8 AVERAGE R
3C - 4.8
3C - 5.8
2C - 4.8
2C - 5.8


Full Scale
Individual Standard Errors
Tenth Scale
C 2+3d — 4.8 + 5.8 AVERAGE R
3d - 4.8
3d - 5.8
2d - 4.8
2d - 5.8

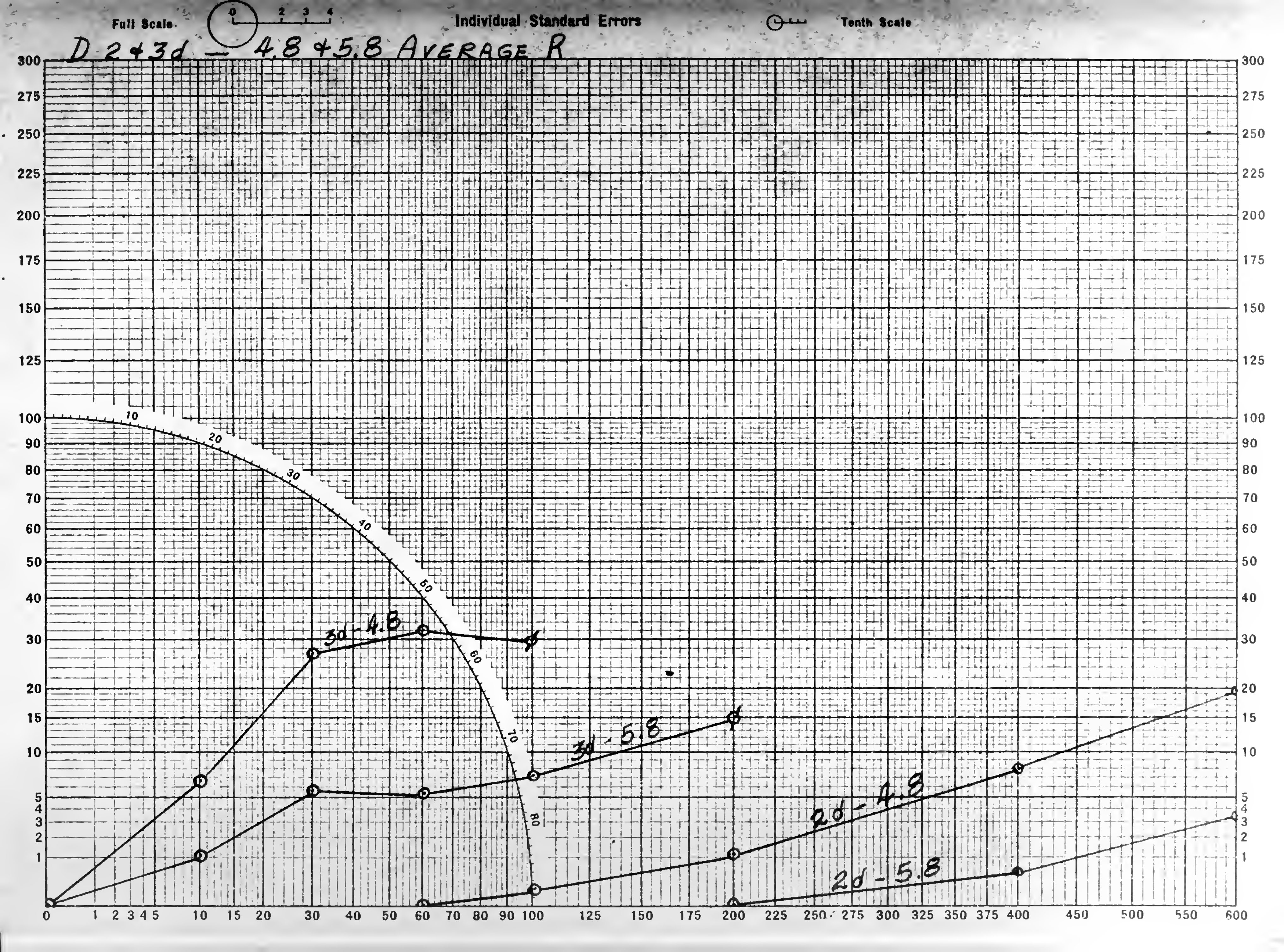

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2a — 4.8 & 5.8 AVERAGE R
2a-4.8
2a-5.8



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D 2 & 3b — 4.8 & 5.8 AVERAGE R
3b-4.8
3b-5.8
2b-4.8
2b-5.8

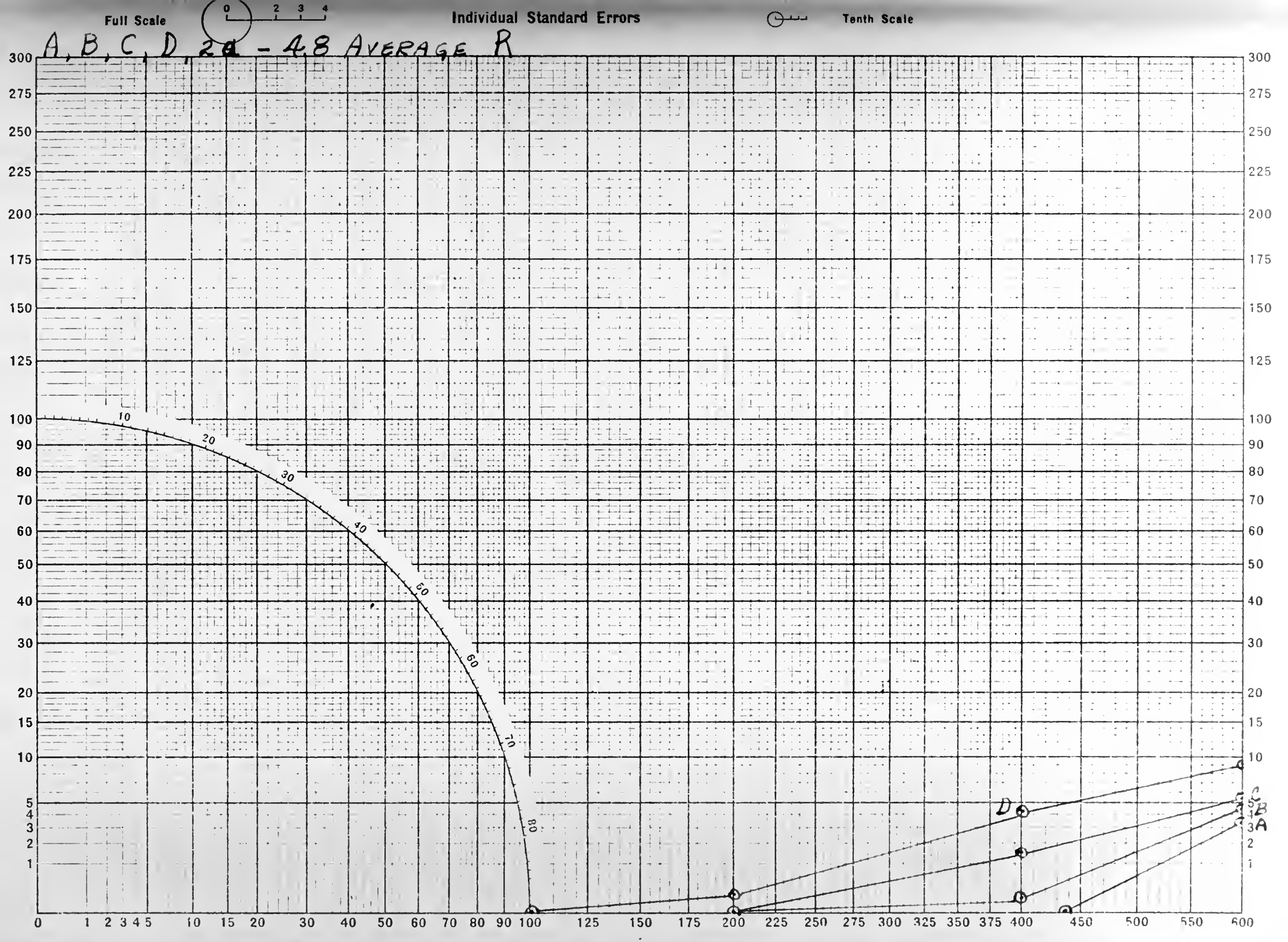


Full Scale
Individual Standard Errors
Tenth Scale
D 2 & 3C — 4.8 & 5.8 AVERAGE R
3C - 4.8
3C - 5.8
2C - 4.8
2C - 5.8


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D 2 & 3d — 4.8 & 5.8 AVERAGE R
3d - 4.8
3d - 5.8
2d - 4.8
2d - 5.8

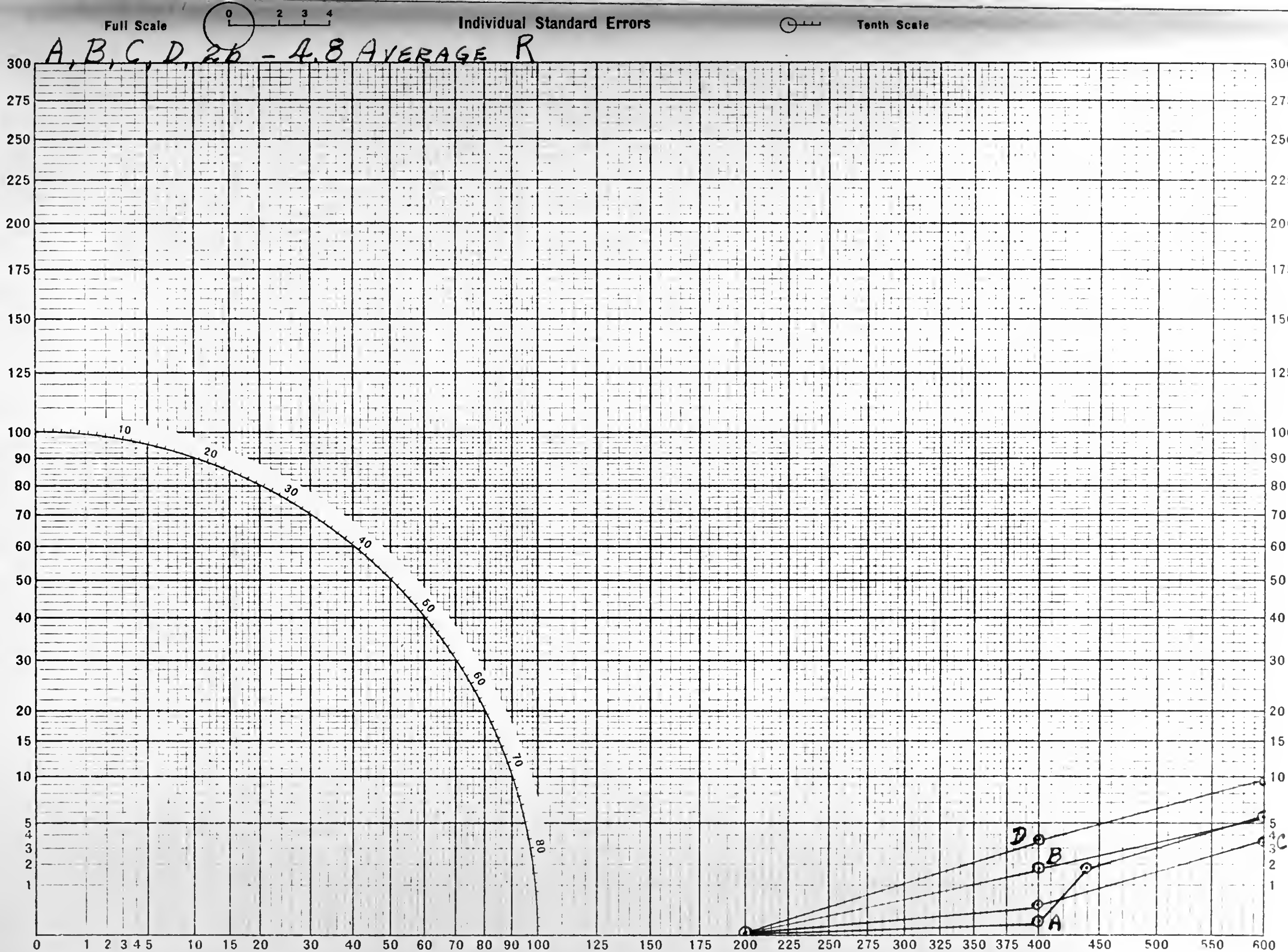
AVERAGE RESISTANCE, COMPARING

PREVIOUS LIFE EXPERIENCE EFFECTS


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A, B, C, D, 2d - 4.8 AVERAGE R
D
C
B
A

Full Scale Individual Standard Errors Tenth Scale

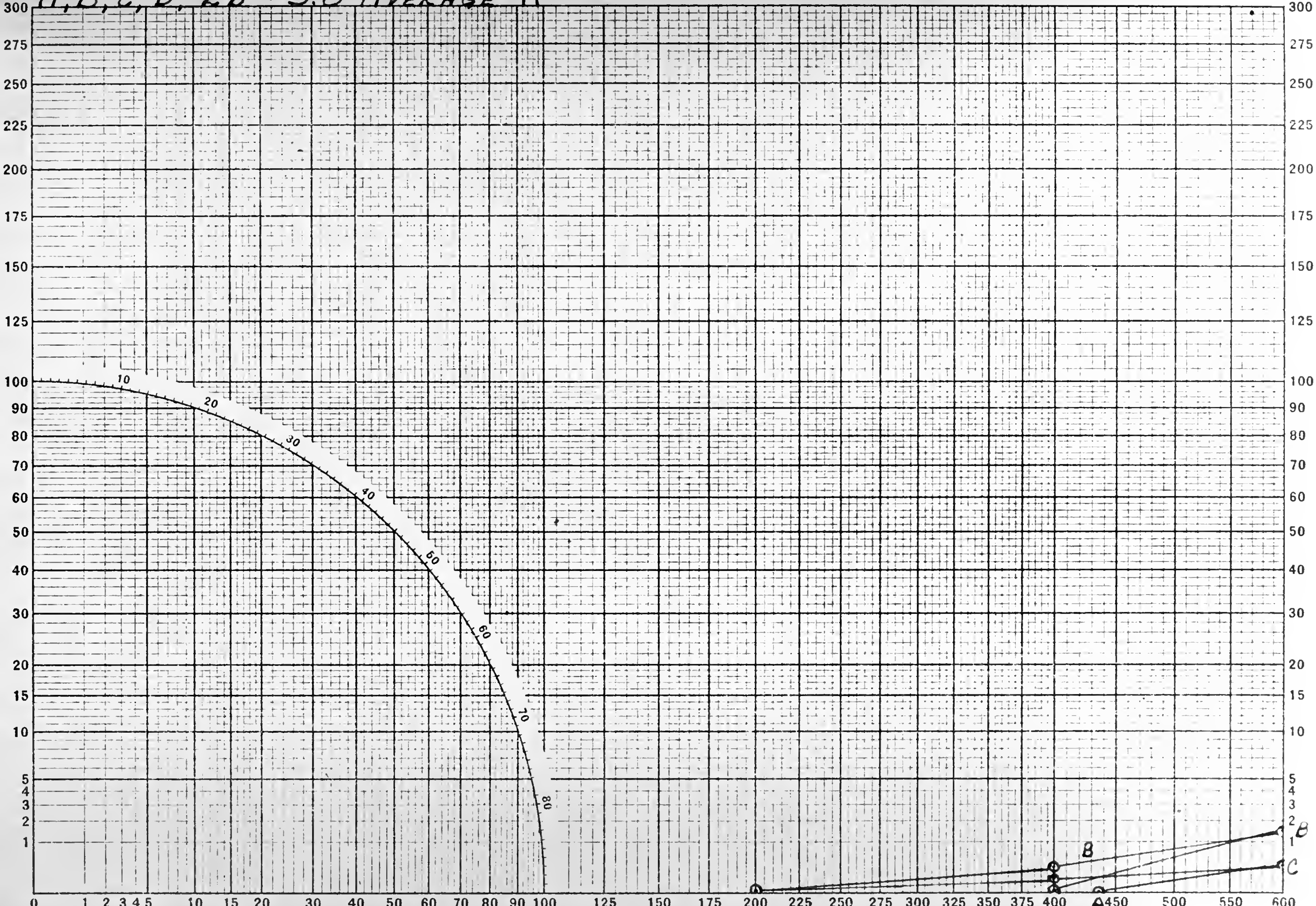
A, B, C, D, 2a - 5.8 AVERAGE R

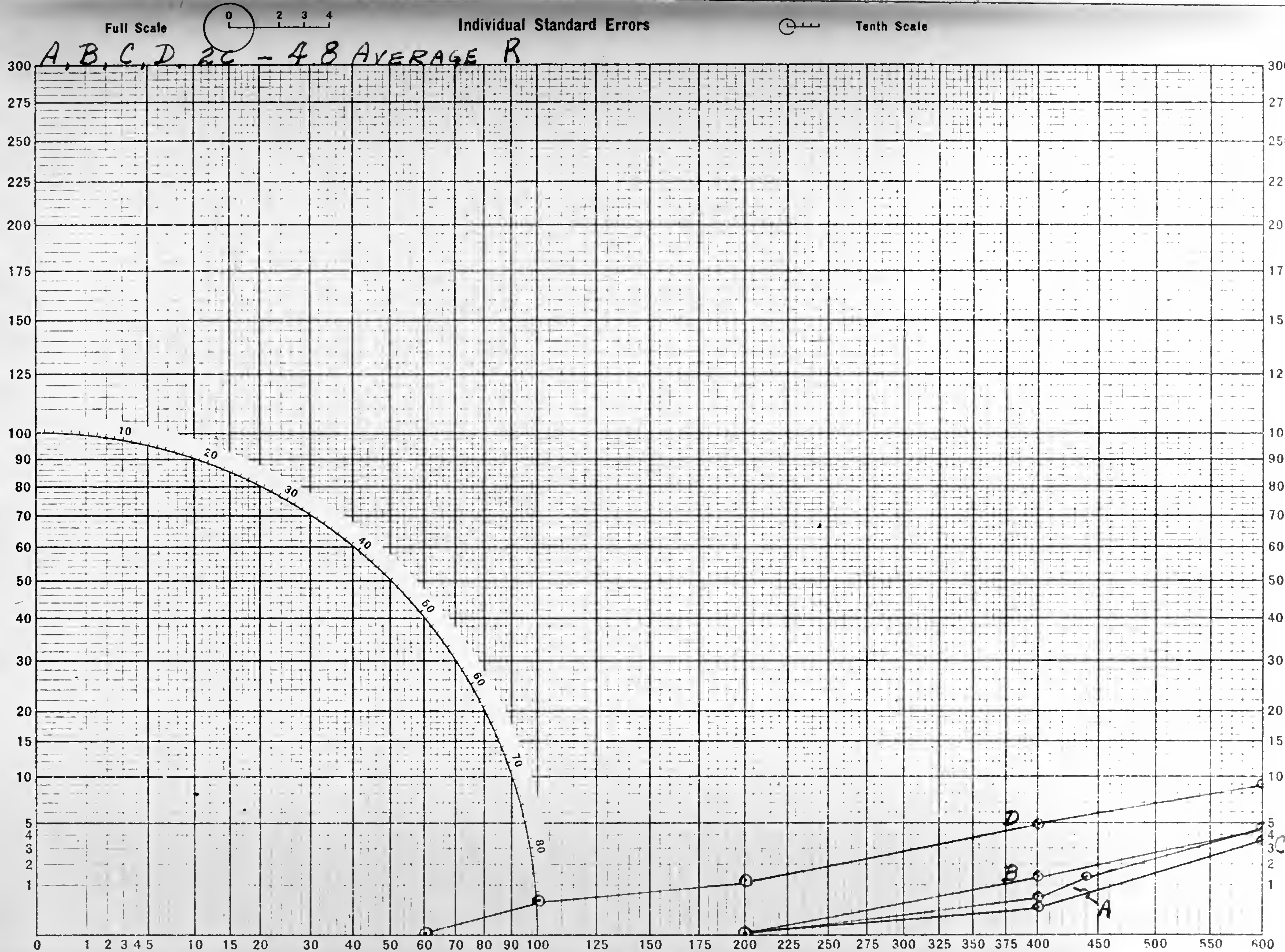


Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D, 2b - 4.8 AVERAGE R
D
B
A
C

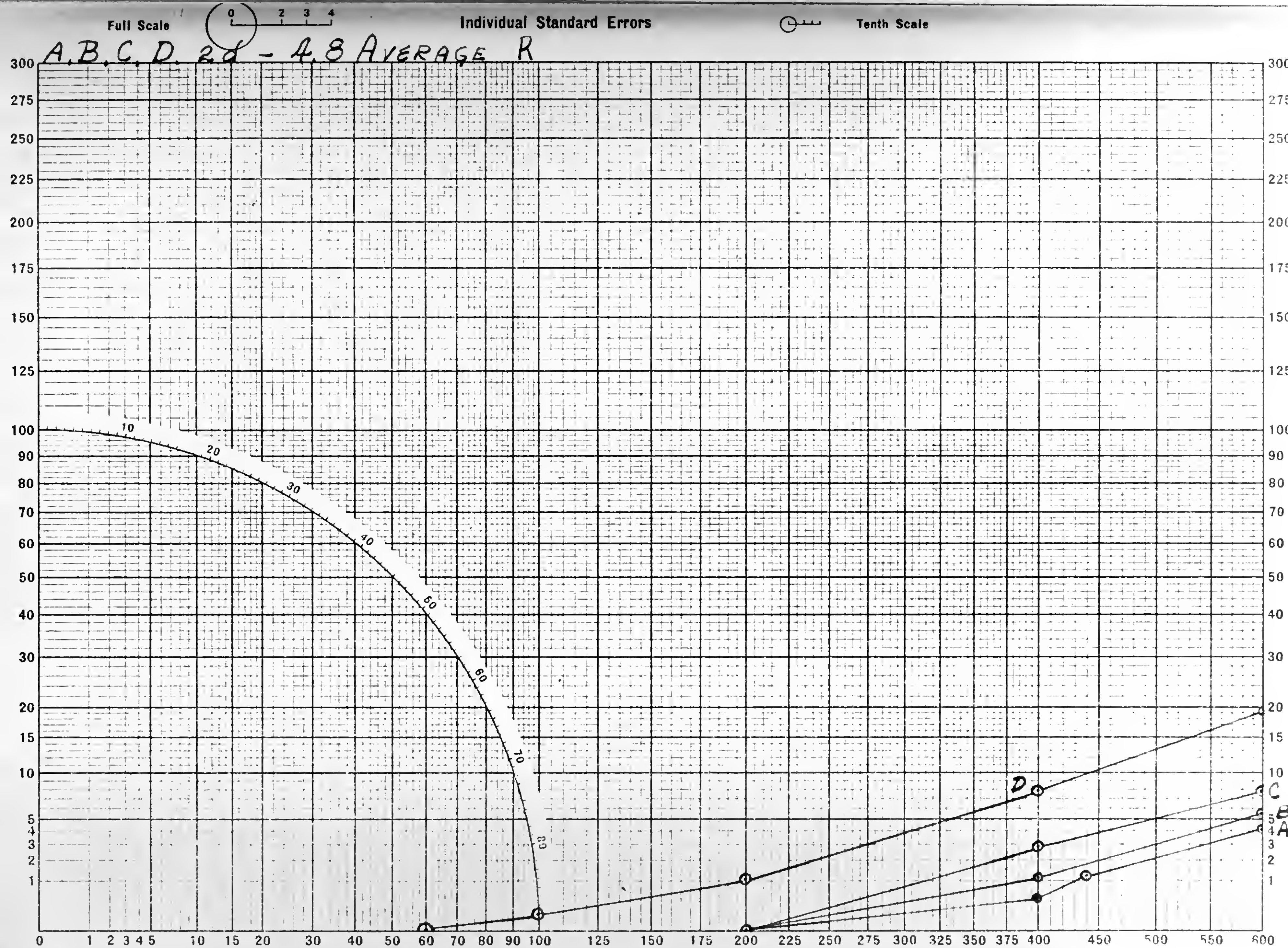
Full Scale Individual Standard Errors Tenth Scale

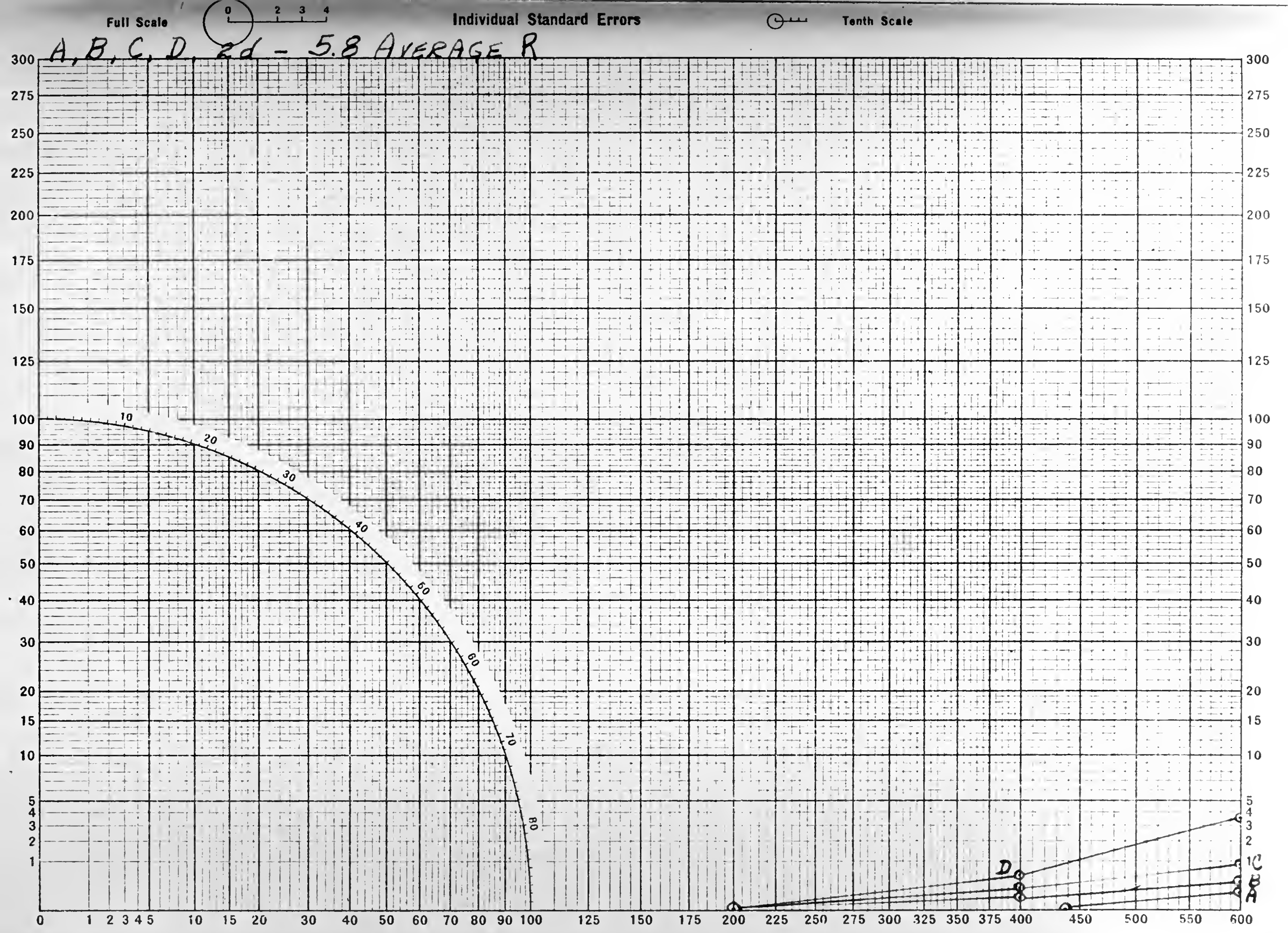
A, B, C, D, 26 - 5.8 AVERAGE R



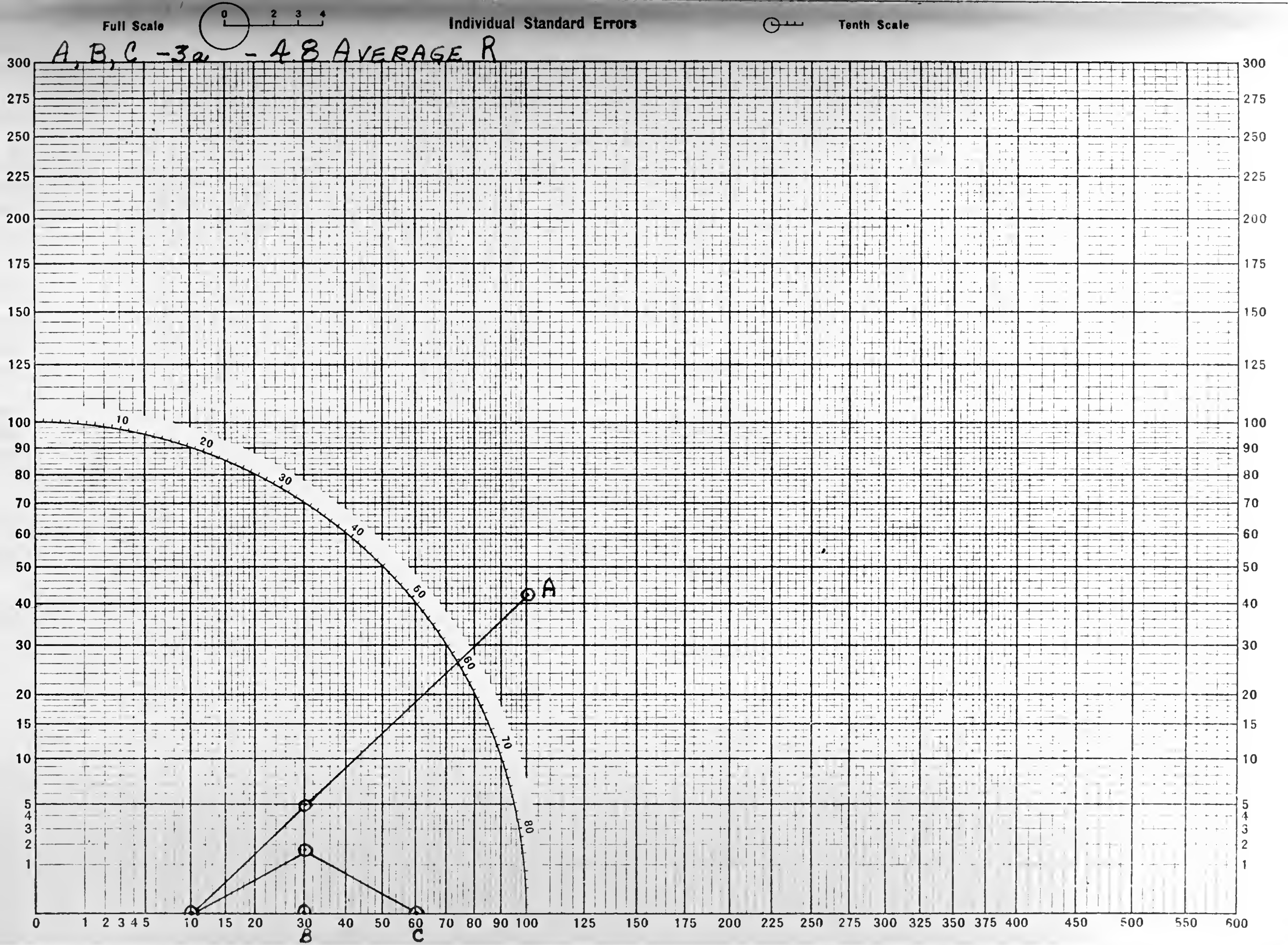

Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D, 2C - 48 AVERAGE R
D
B
A
C


Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 2c - 5.8 Average R
B
A
C
D


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A.B.C.D. 2d - 4.8 AVERAGE R
D
C
B
A



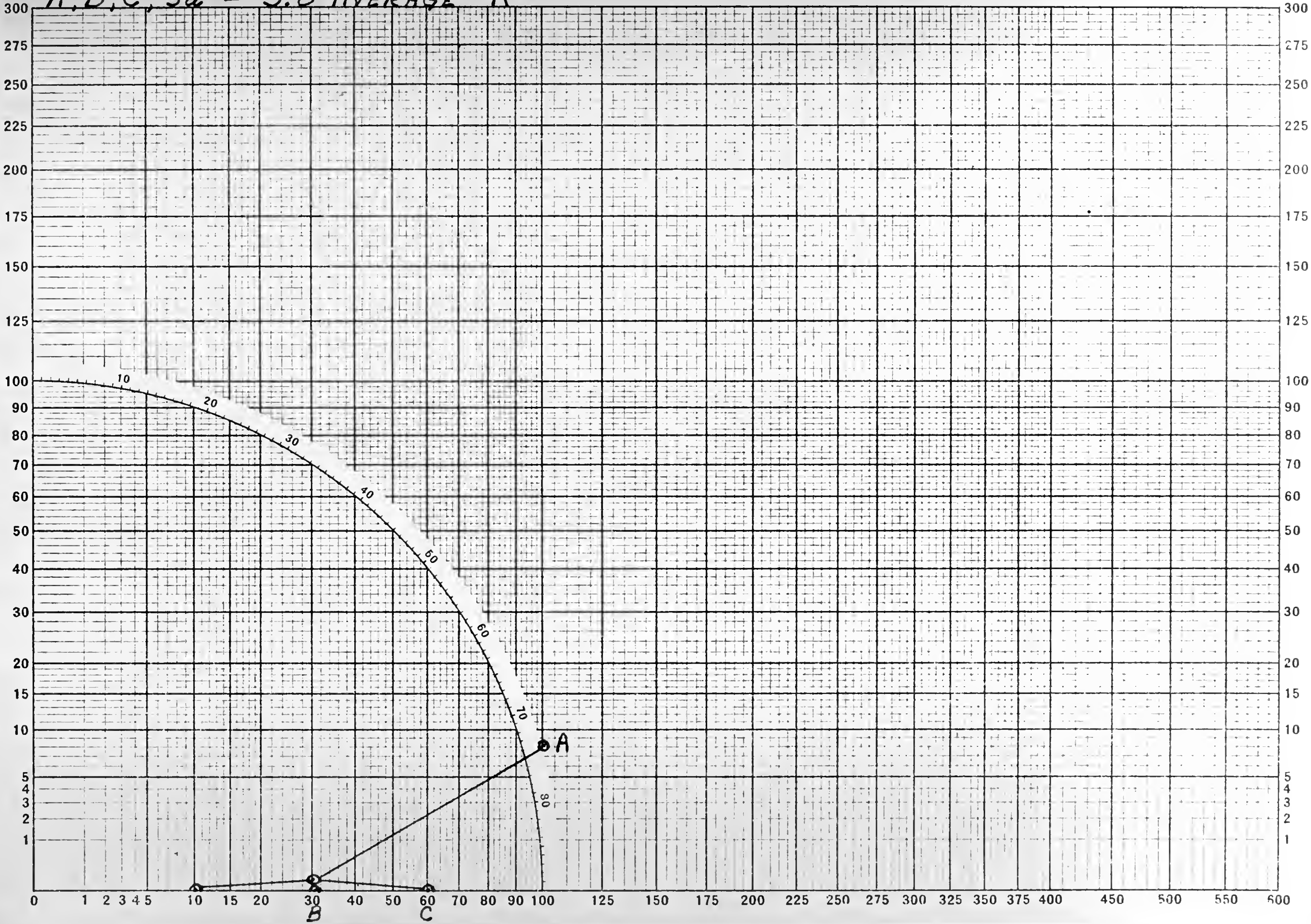
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D, 2d - 5.8 AVERAGE R
D
C
B
A

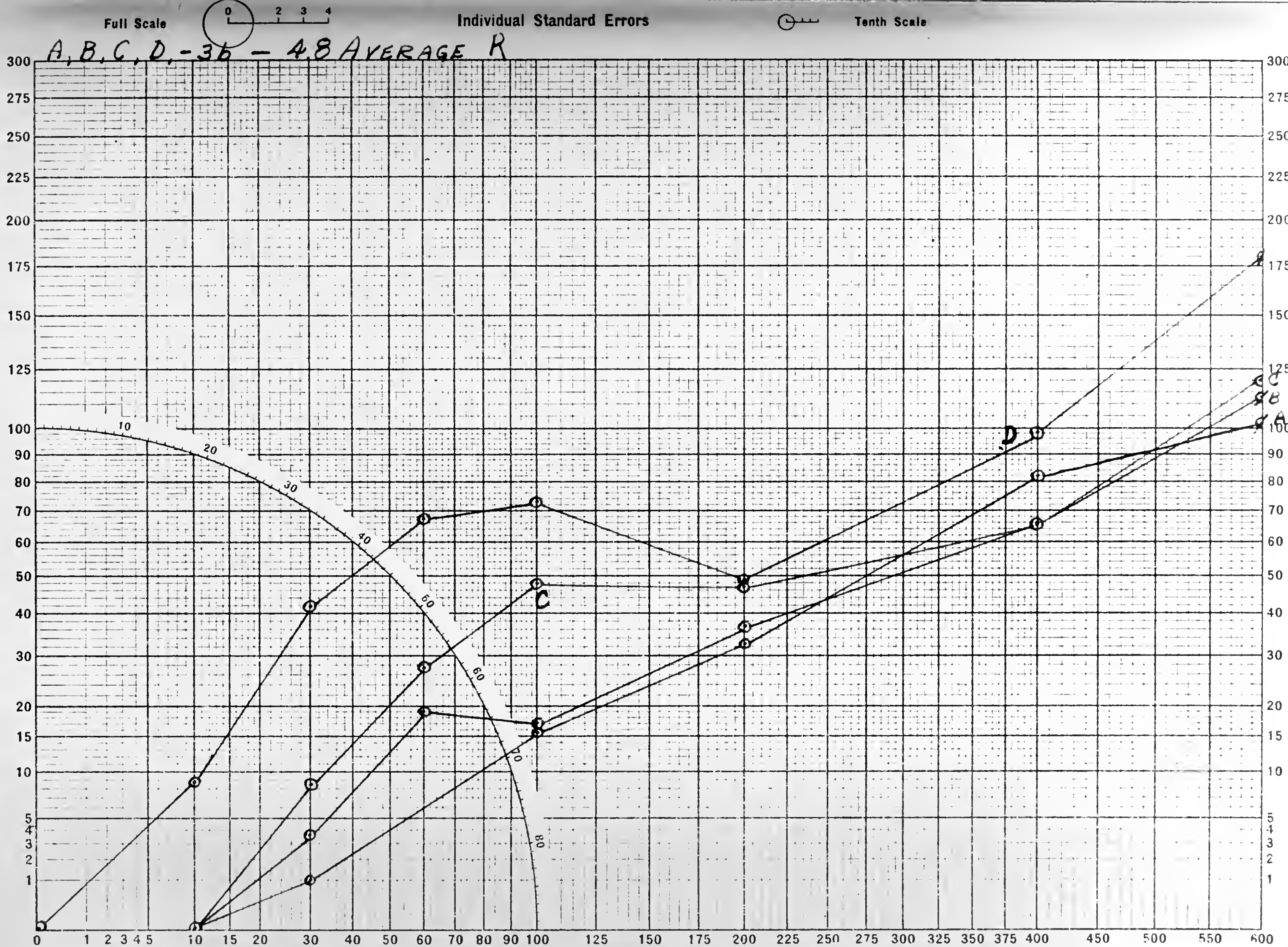


Full Scale
Individual Standard Errors
Tenth Scale
A, B, C -3σ - 4.8 AVERAGE R
A
B
C

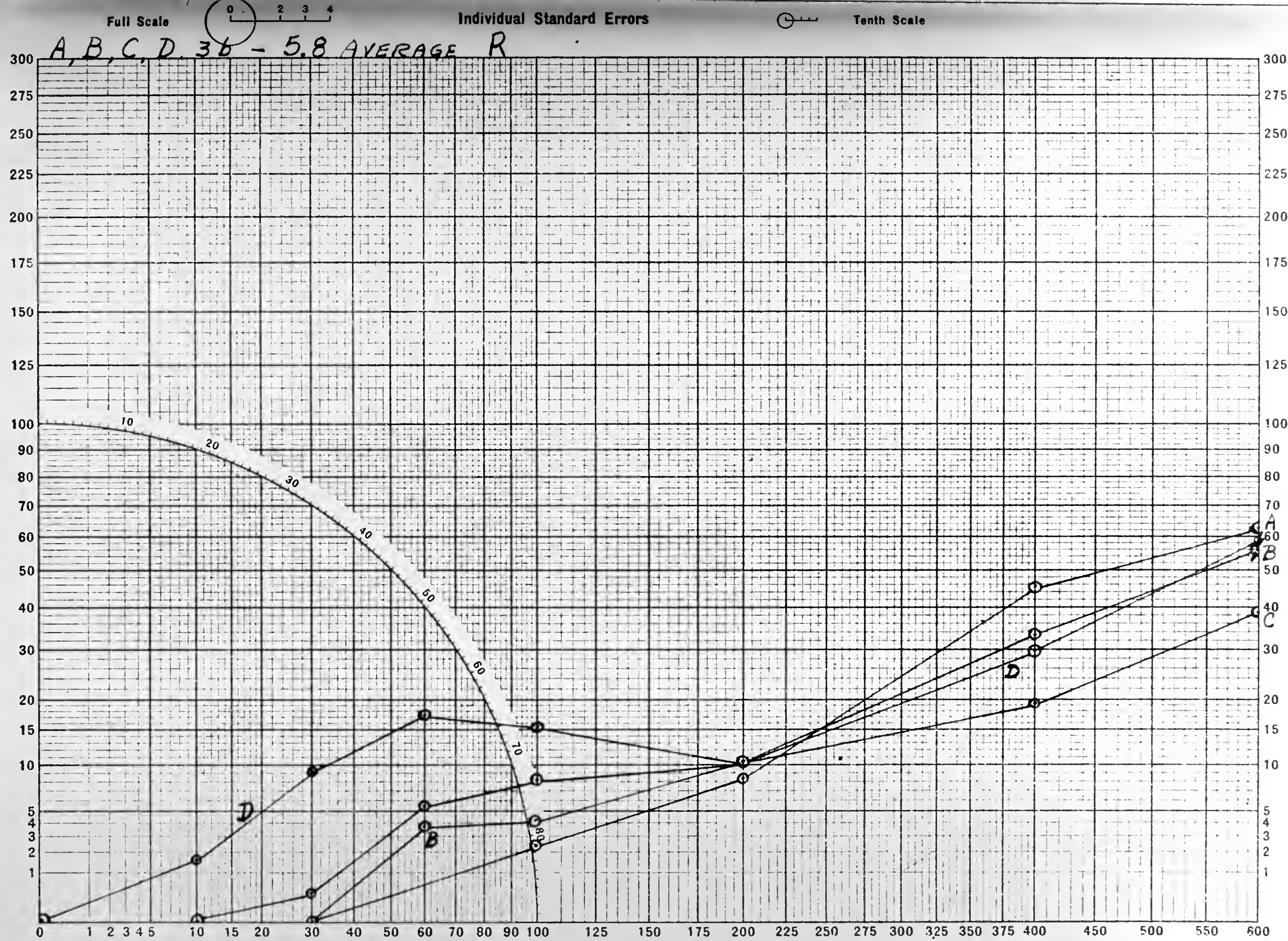
Full Scale Individual Standard Errors Tenth Scale

A, B, C, 3a = 5.8 AVERAGE R

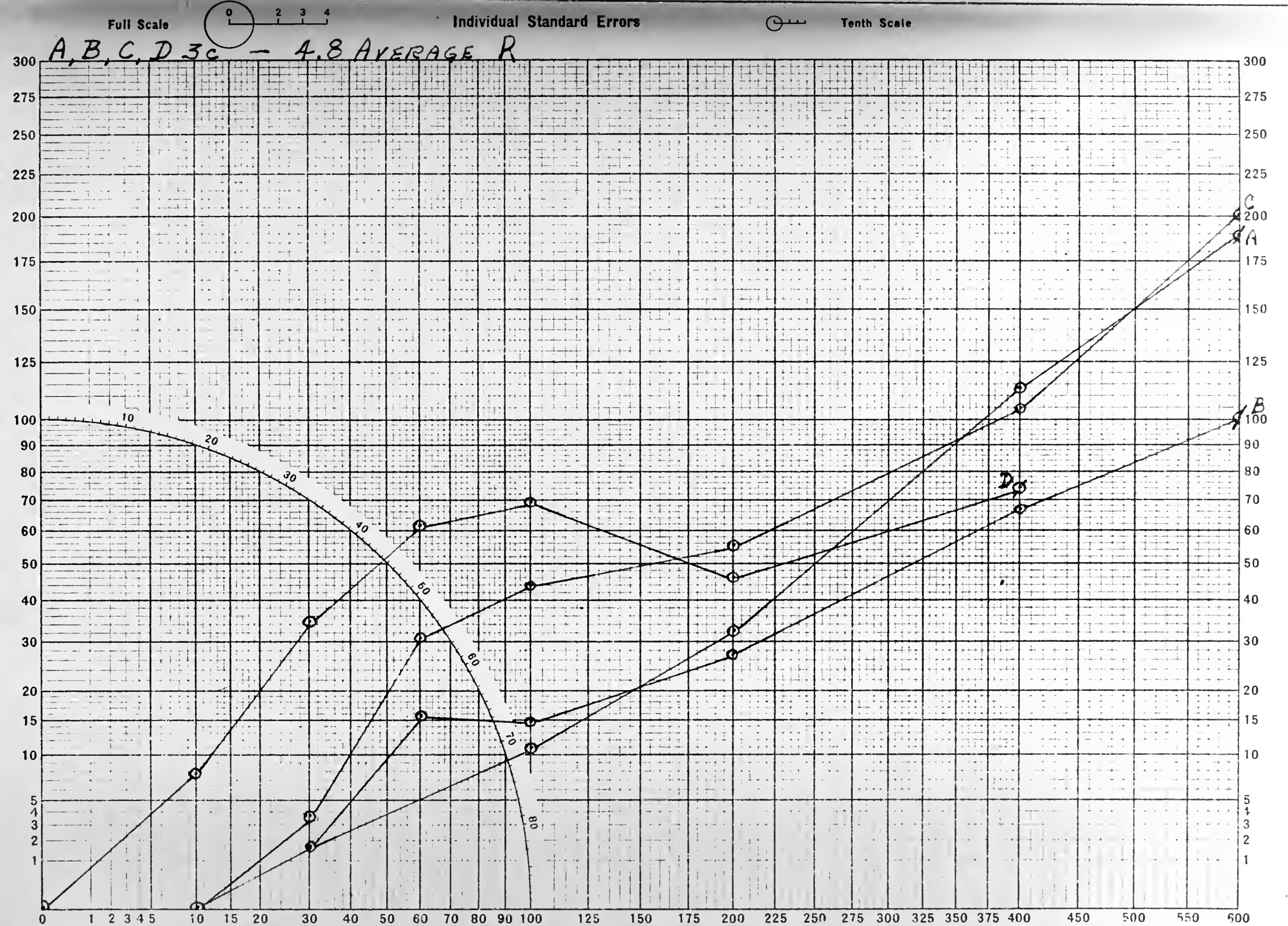




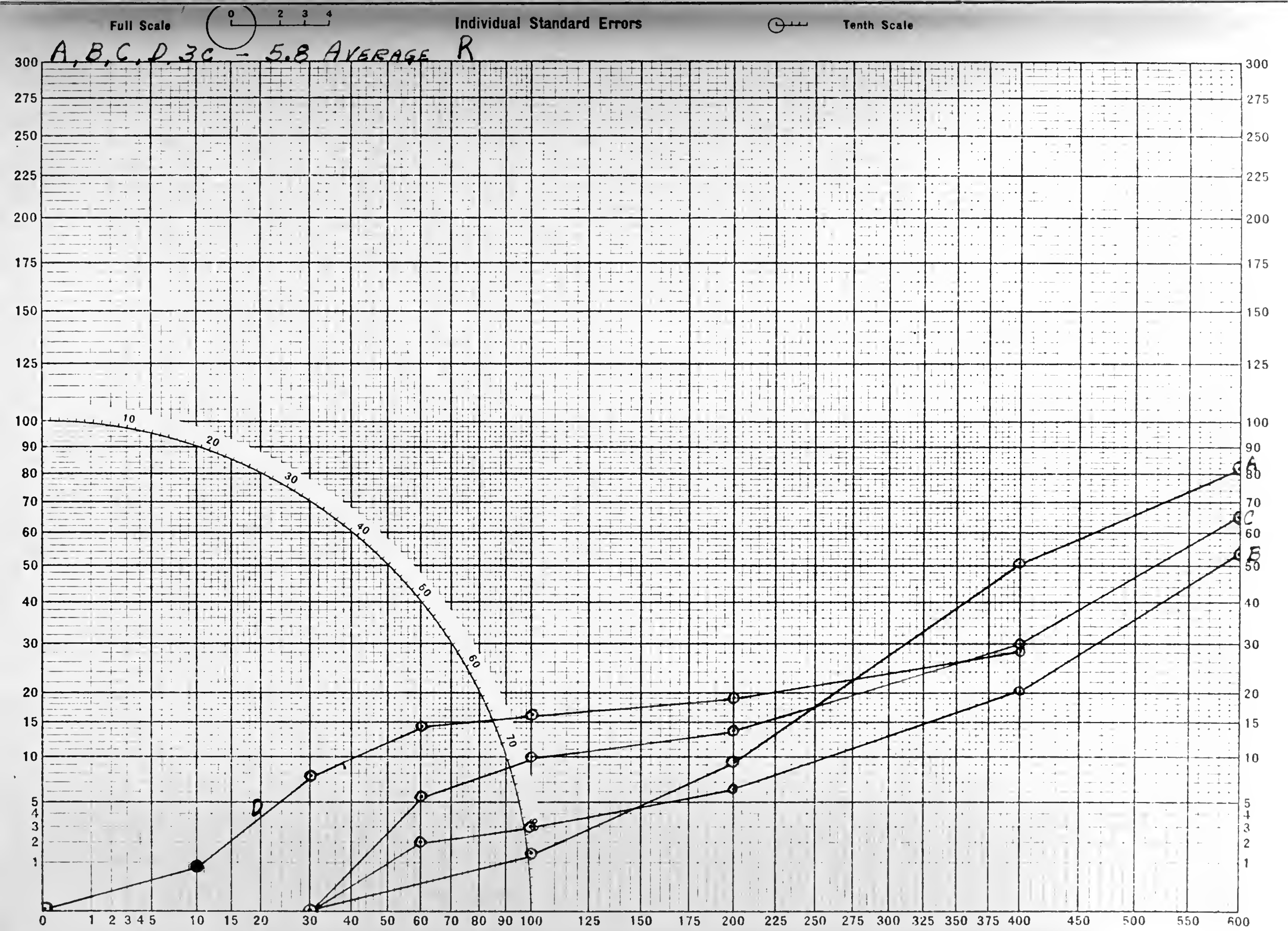
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D, -3b - 4.8 AVERAGE R
C
D
A
B
C



Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D. 36 - 5.8 AVERAGE R
A
B
C
D
D
B



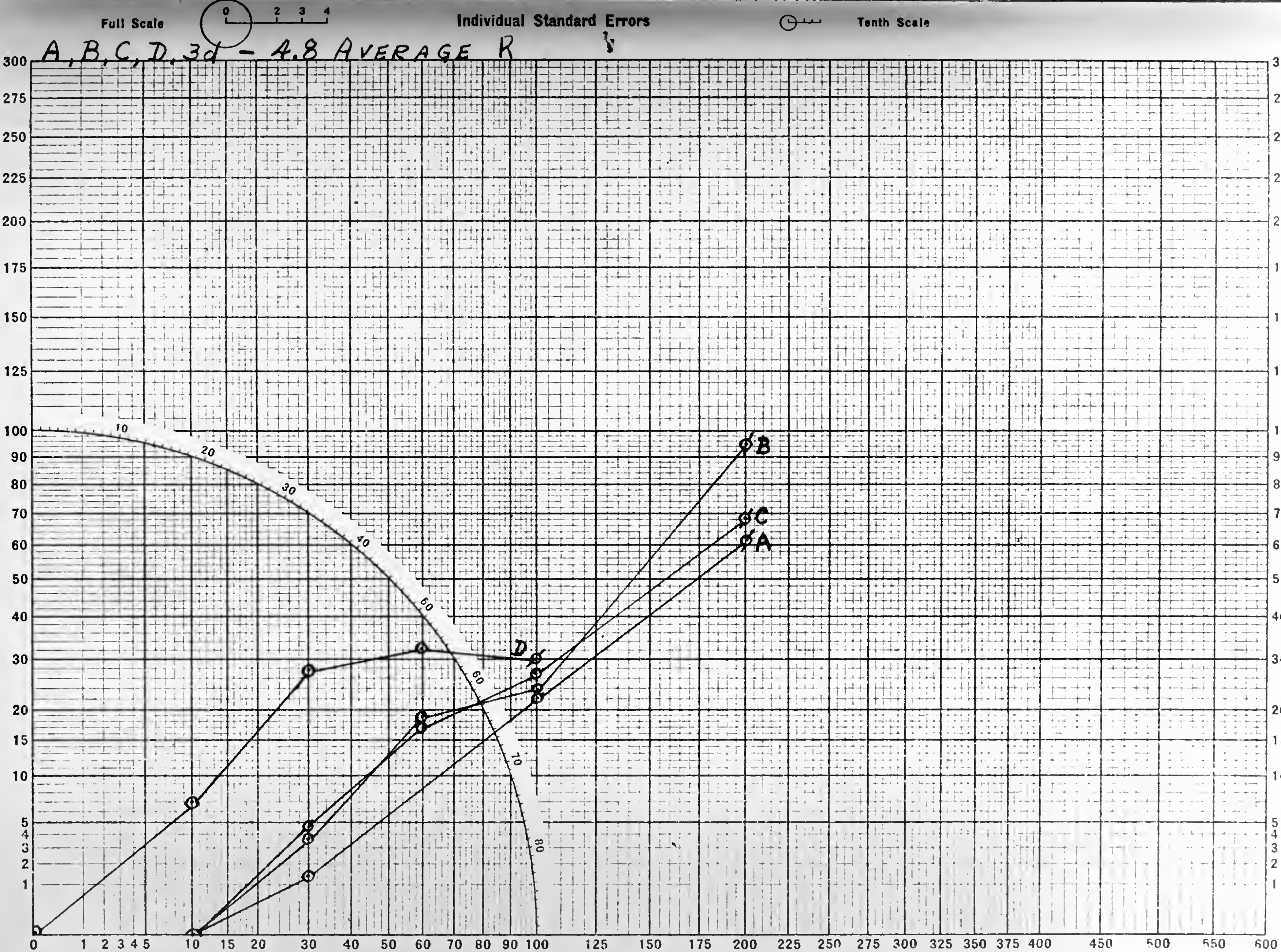
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 3c — 4.8 AVERAGE R
C
A
B
D

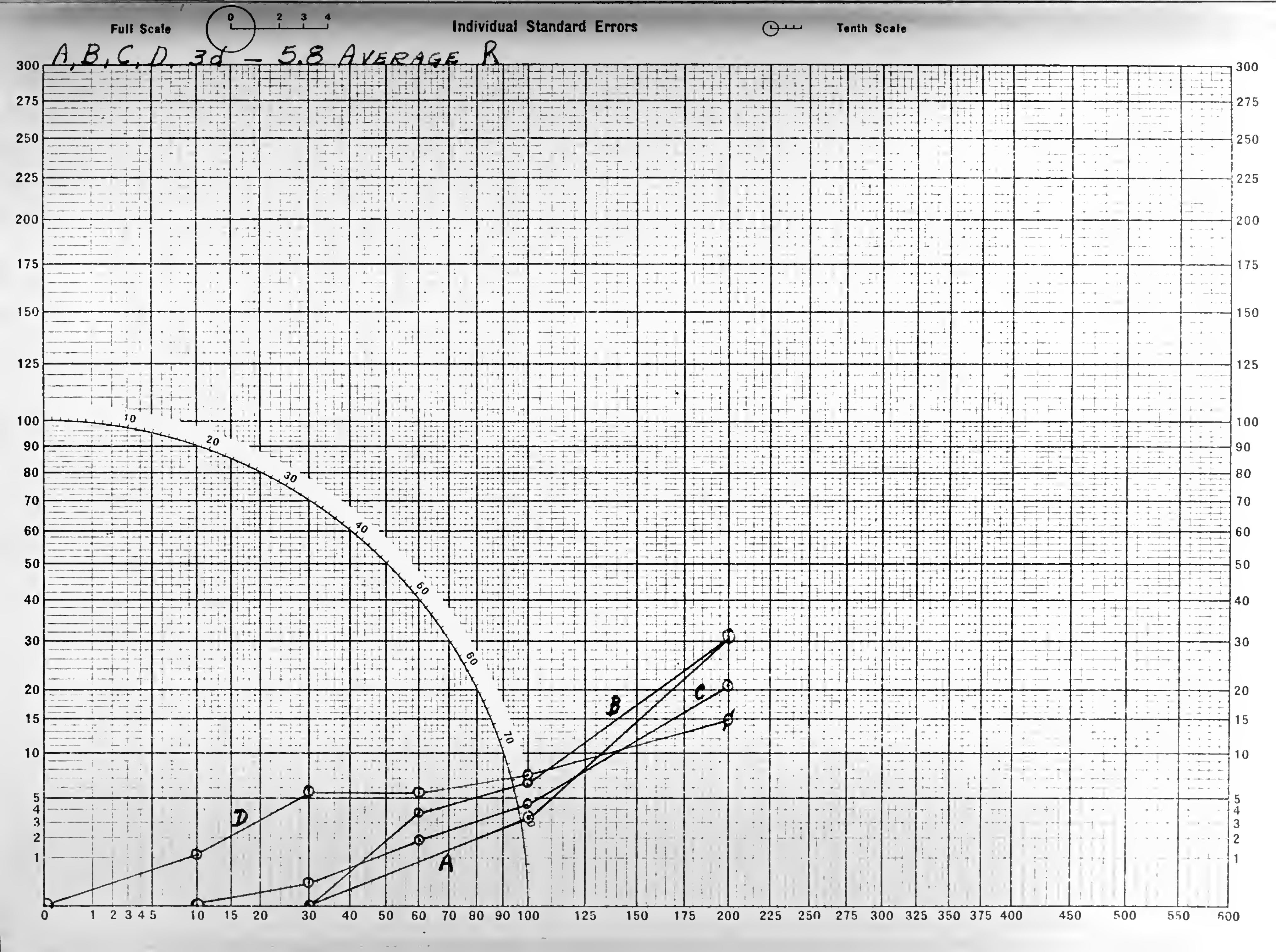


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A, B, C, D, 3C - 5.8 AVERAGE R
A
C
B
D

Full Scale | Individual Standard Errors | Tenth Scale

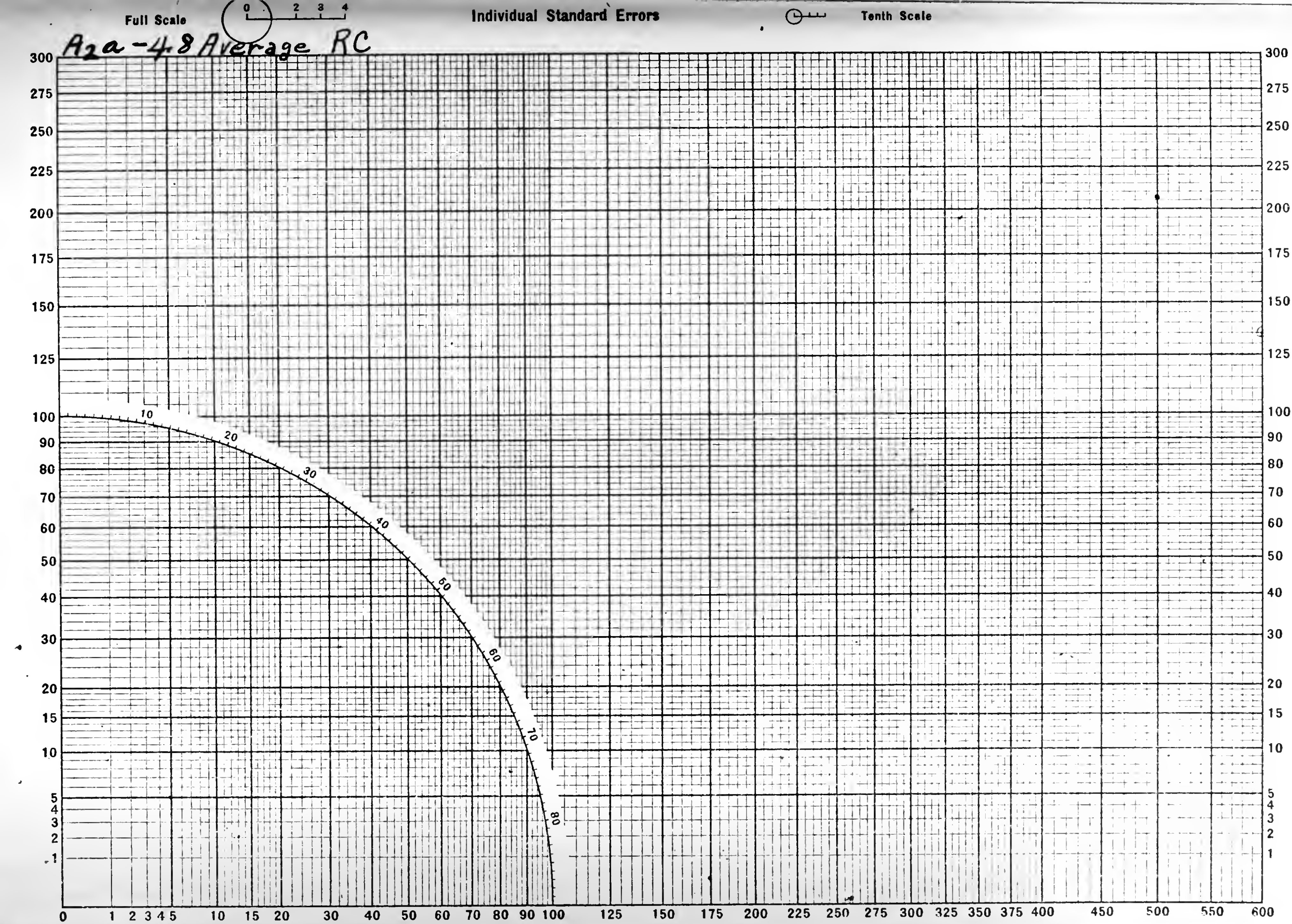
A, B, C, D, 3d - 4.8 AVERAGE R





Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D. 3d – 5.8 AVERAGE R
A
B
C
D

AVERAGE TIME CONSTANT, SINGLE GROUP

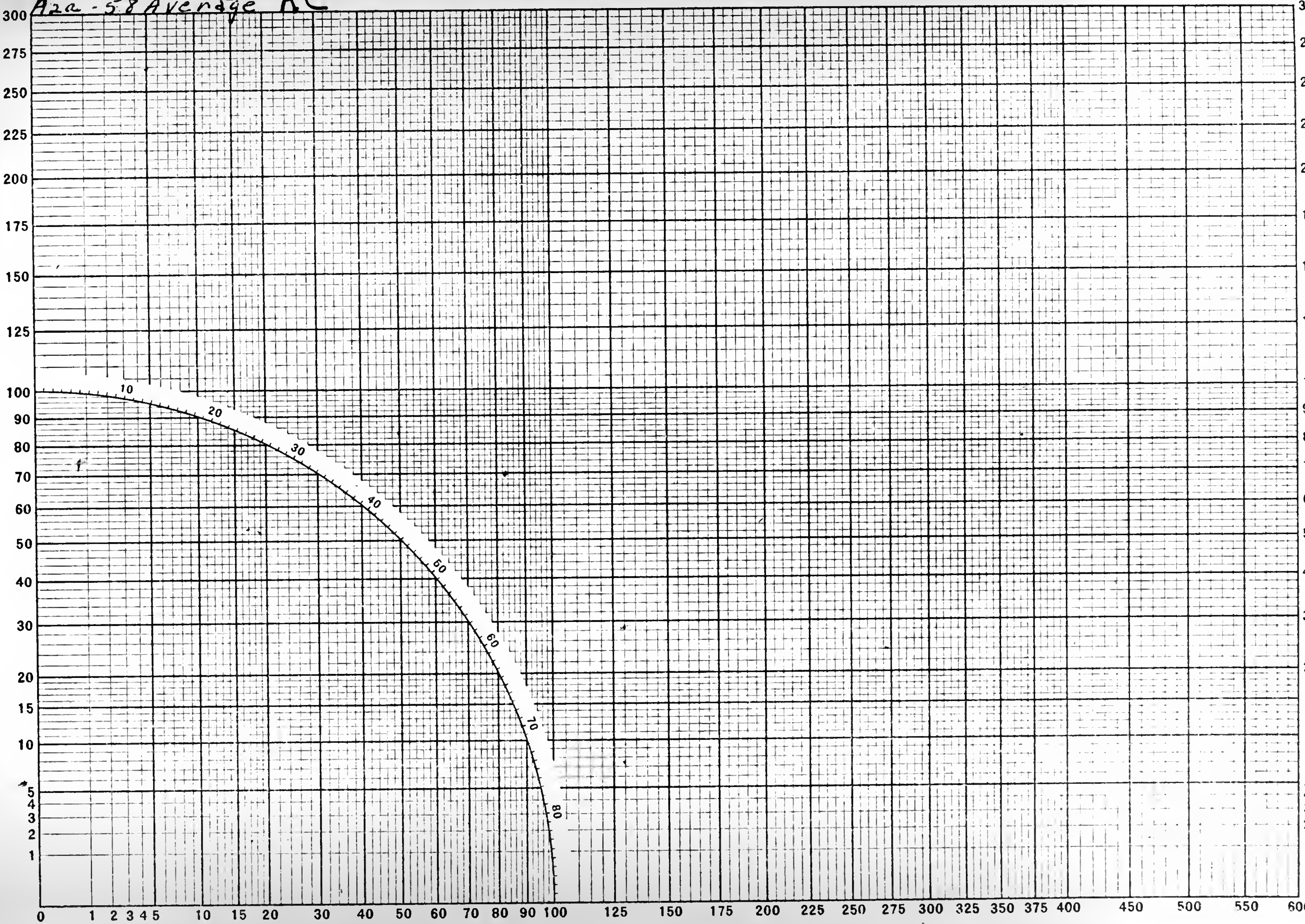

Full Scale
Individual Standard Errors
Tenth Scale
A2a-4.8 Average RC

Full Scale

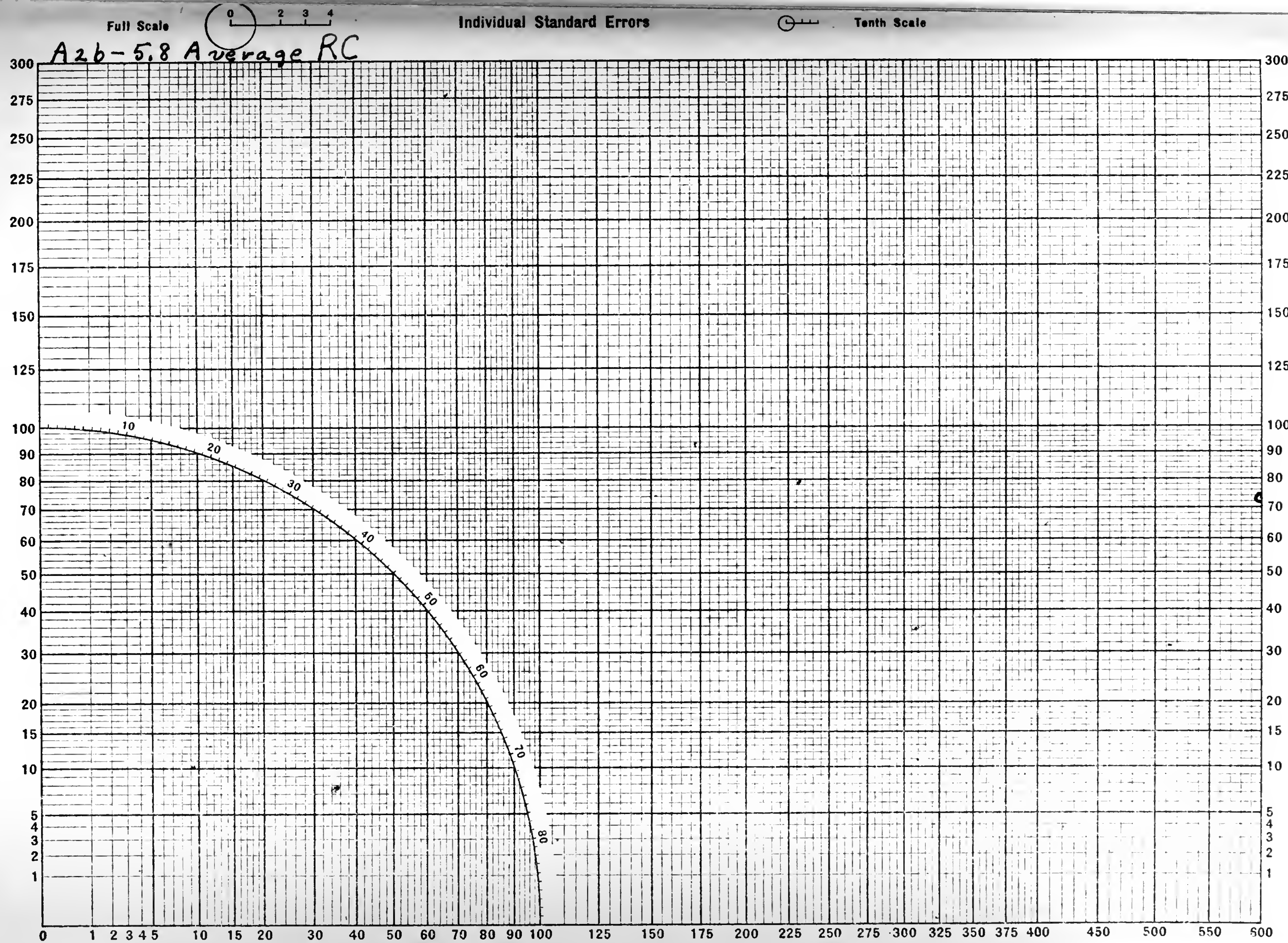
Individual Standard Errors

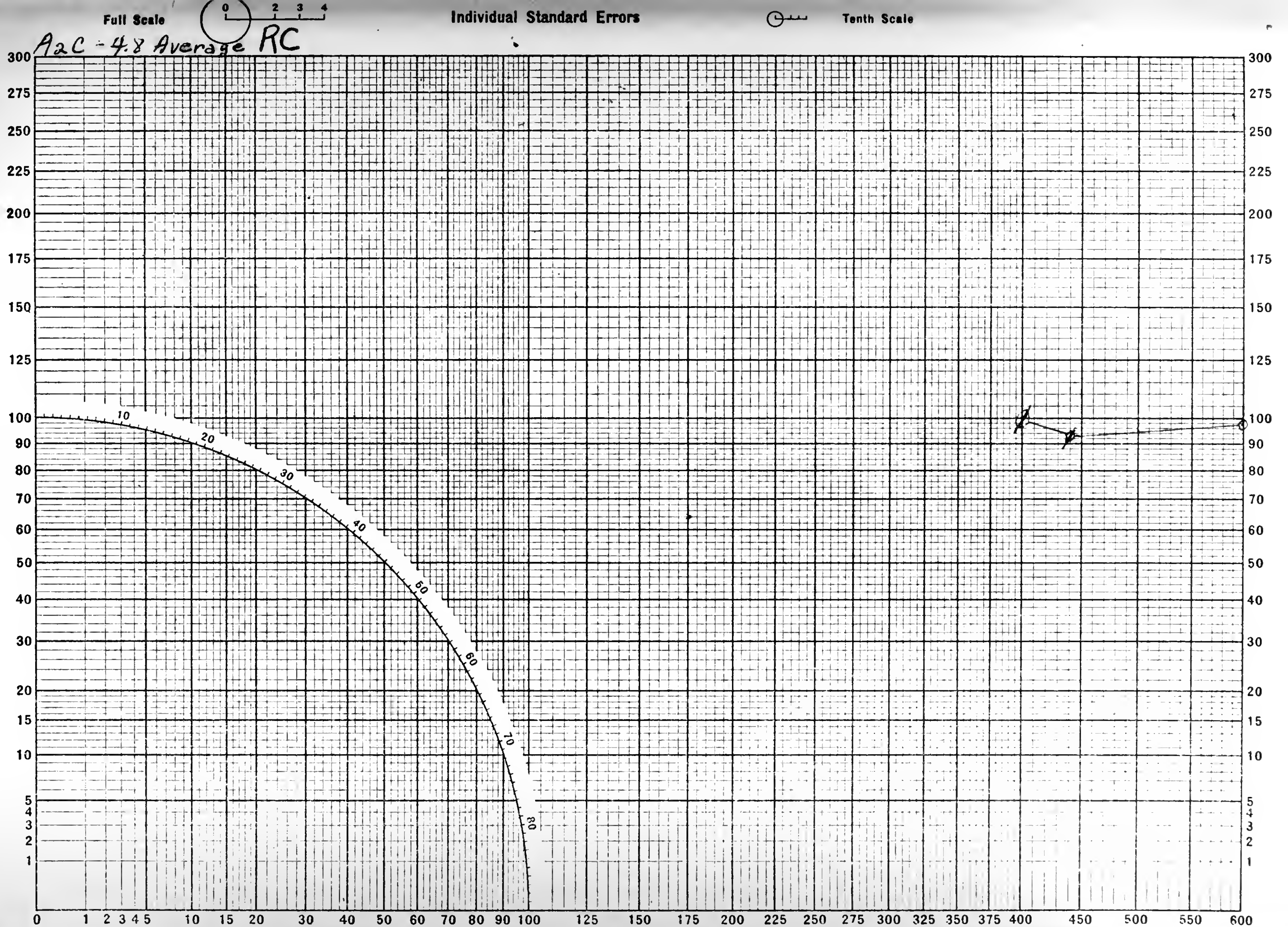
Tenth Scale

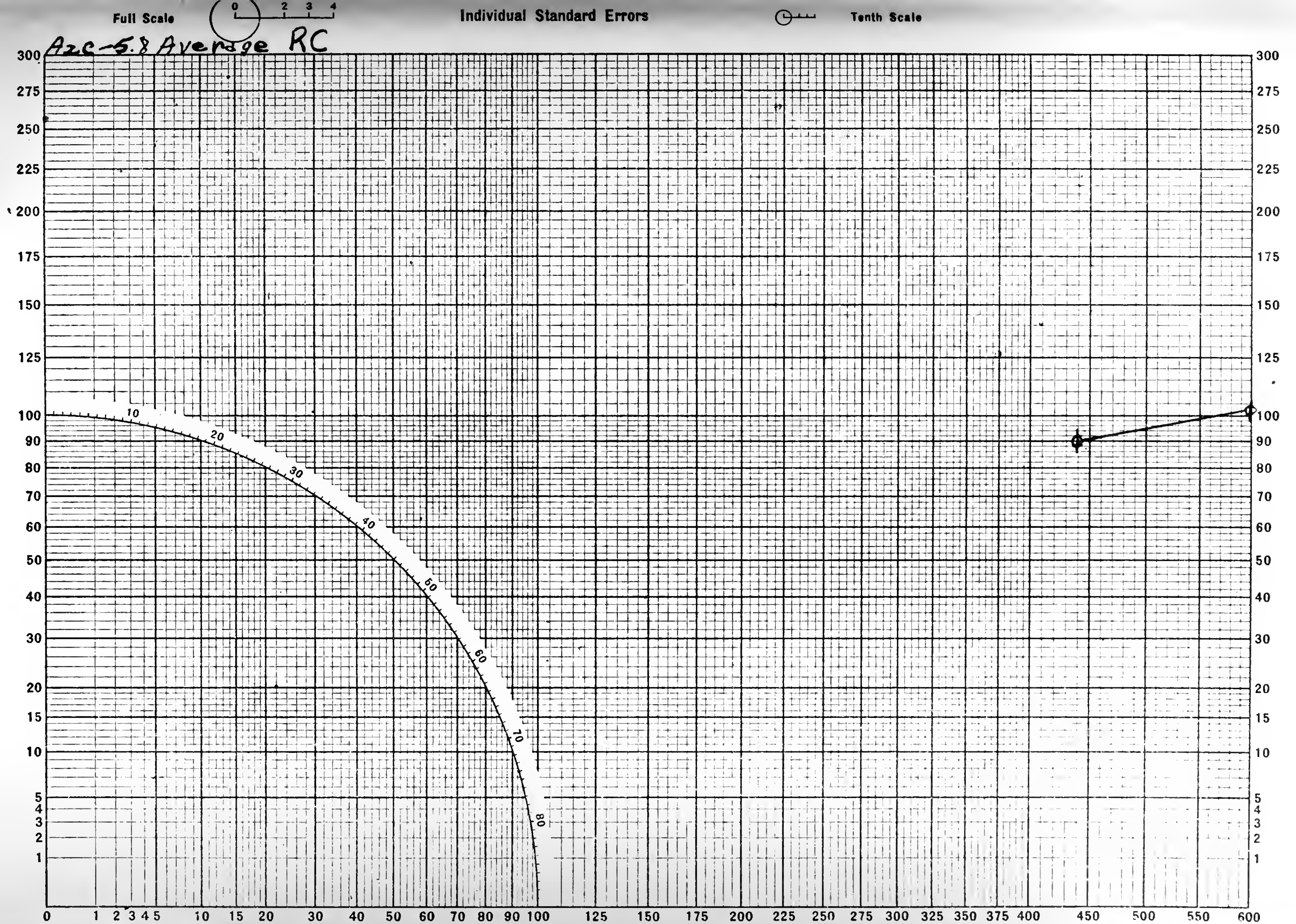
Aza-58 Average RC



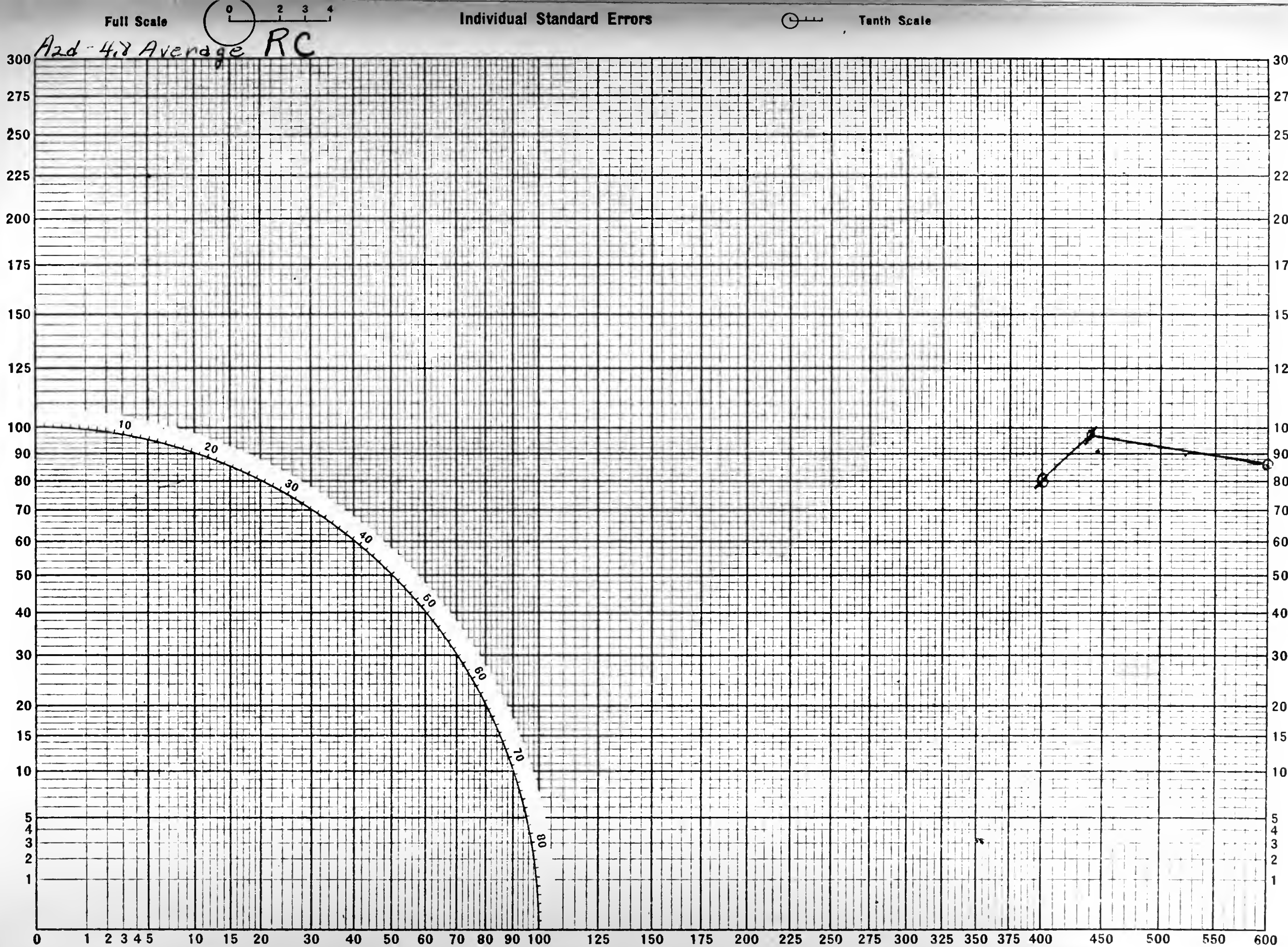

Full Scale
Individual Standard Errors
Tenth Scale
A2b 4.8 Average RC


Full Scale
Individual Standard Errors
Tenth Scale
A2b-5.8 Average RC

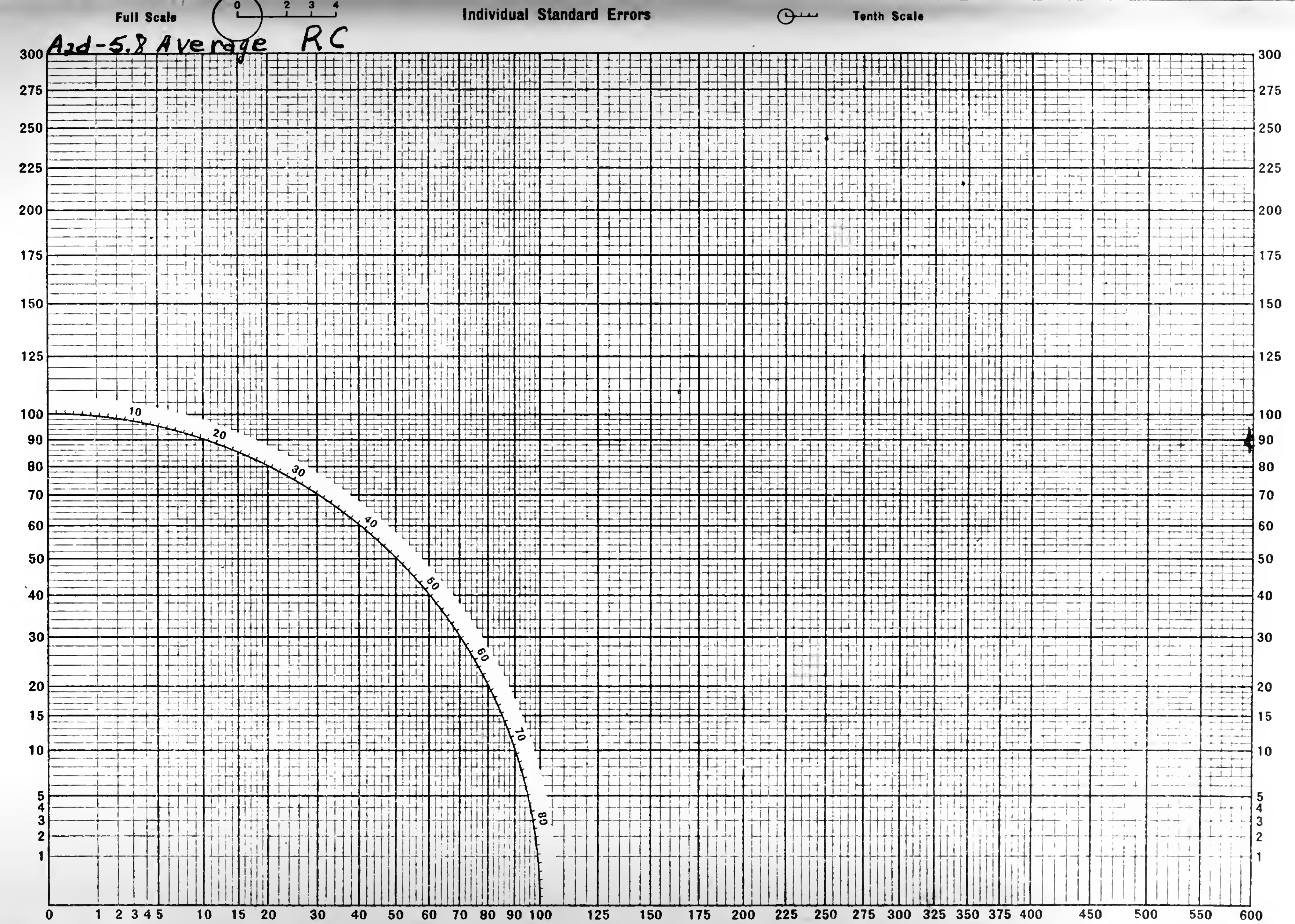

Full Scale
Individual Standard Errors
Tenth Scale
A2C - 4.8 Average RC

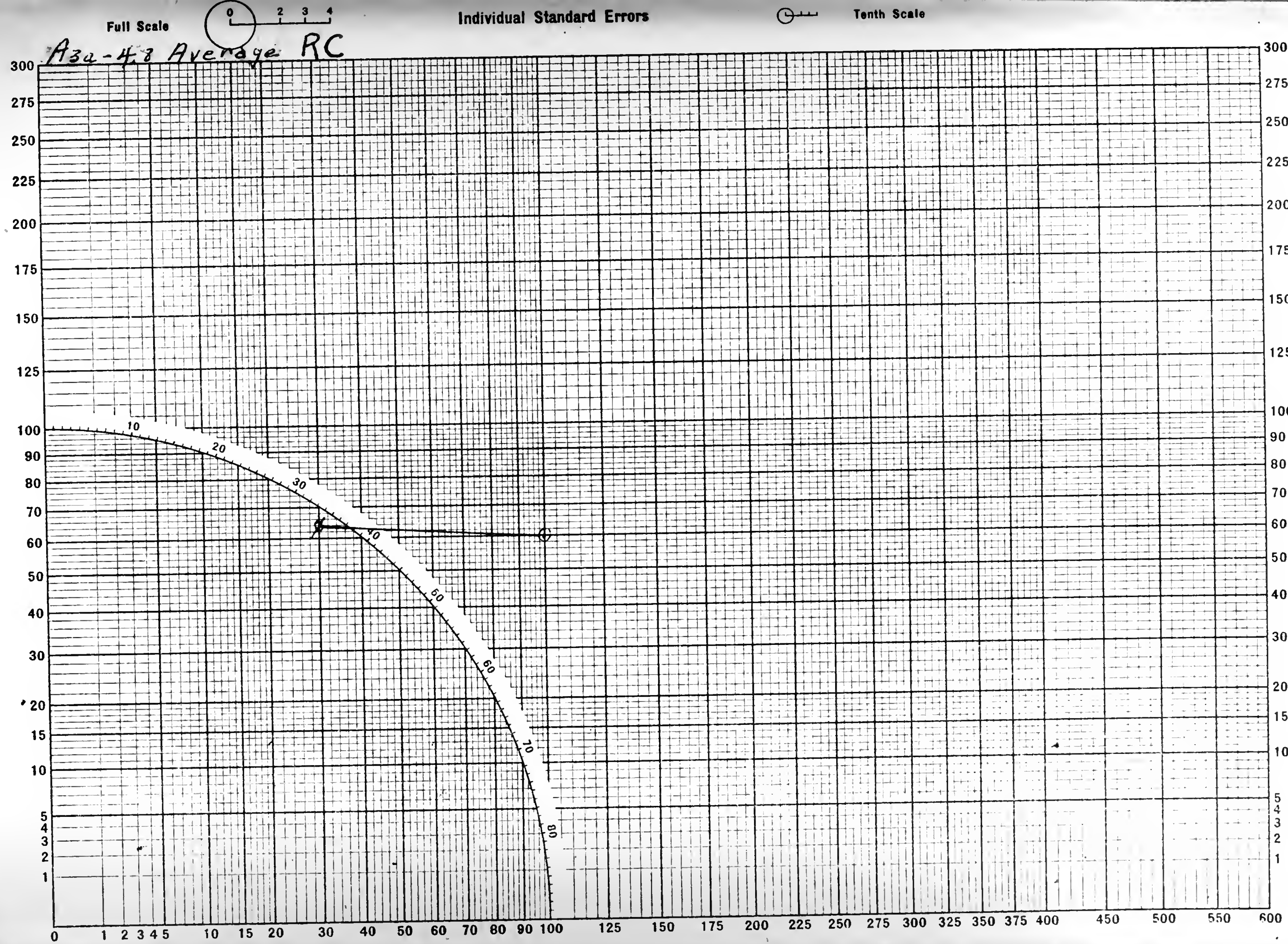


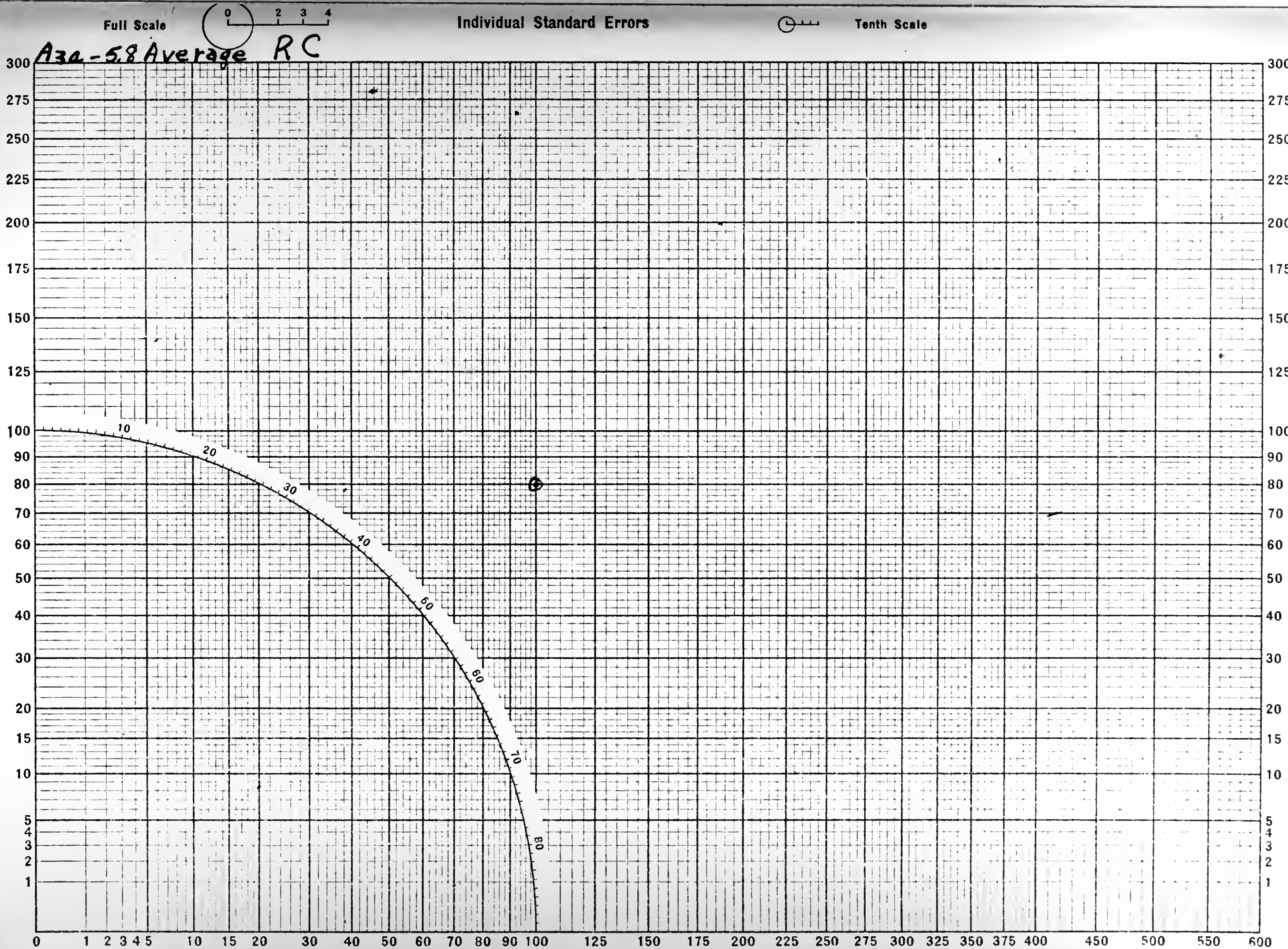
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
Azc-5.8 Average RC



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A2d - 4.8 Average RC

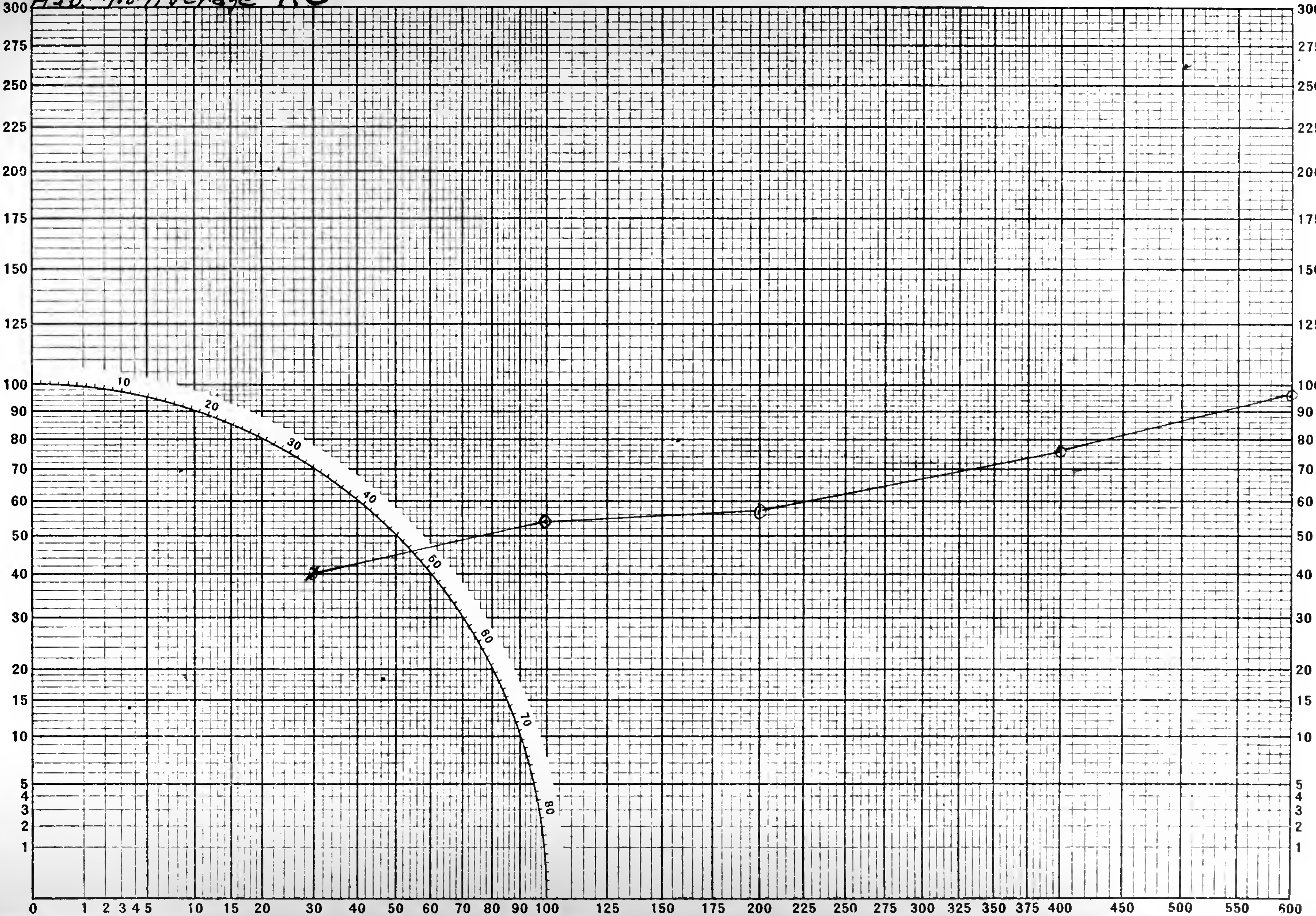

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A2d-5.8 Average RC
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80


Full Scale
Individual Standard Errors
Tenth Scale
A3a-4.8 Average RC

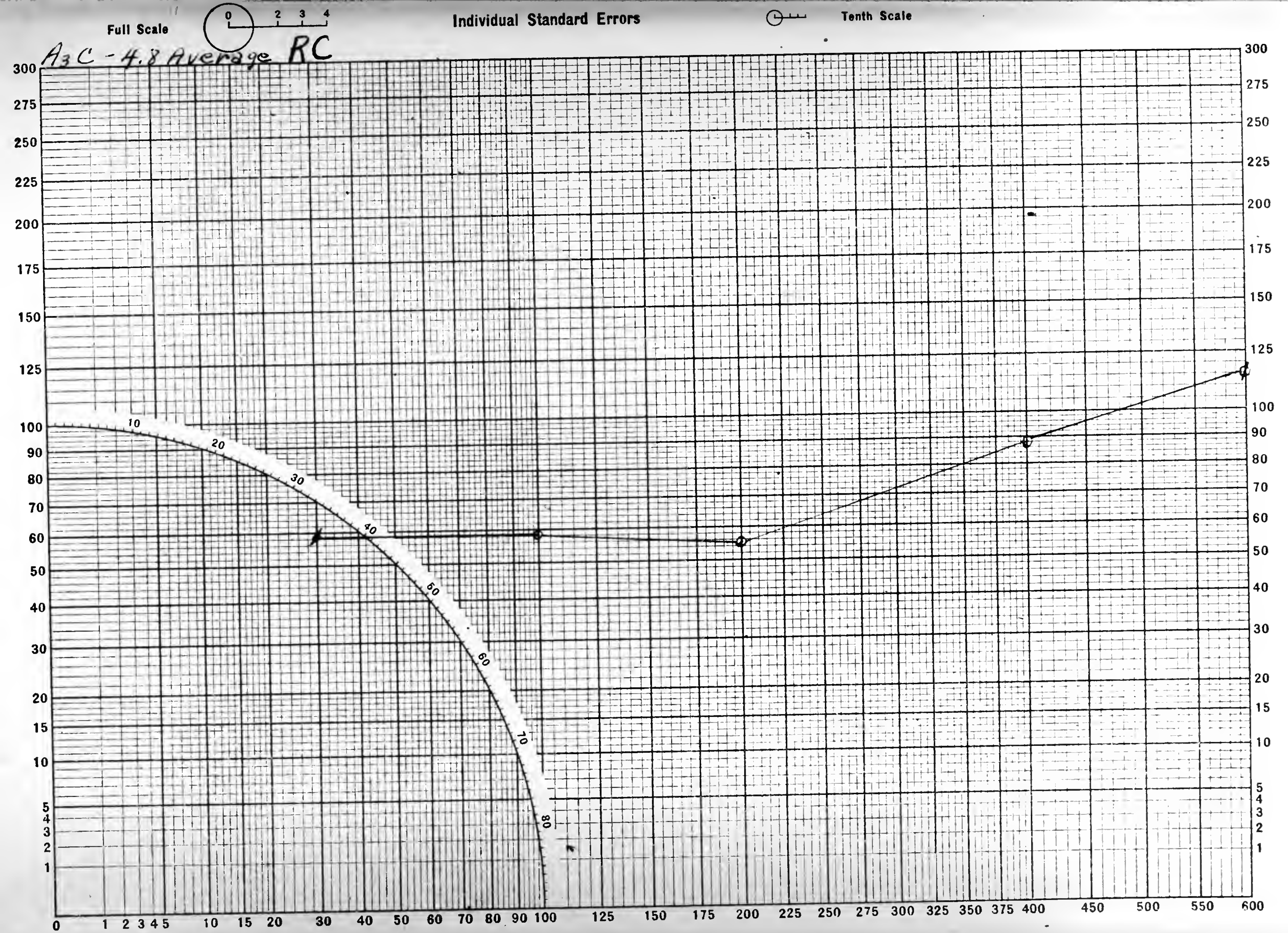

Full Scale
Individual Standard Errors
Tenth Scale
A3a-5.8 Average RC
10
20
30
40
50
60
70
80

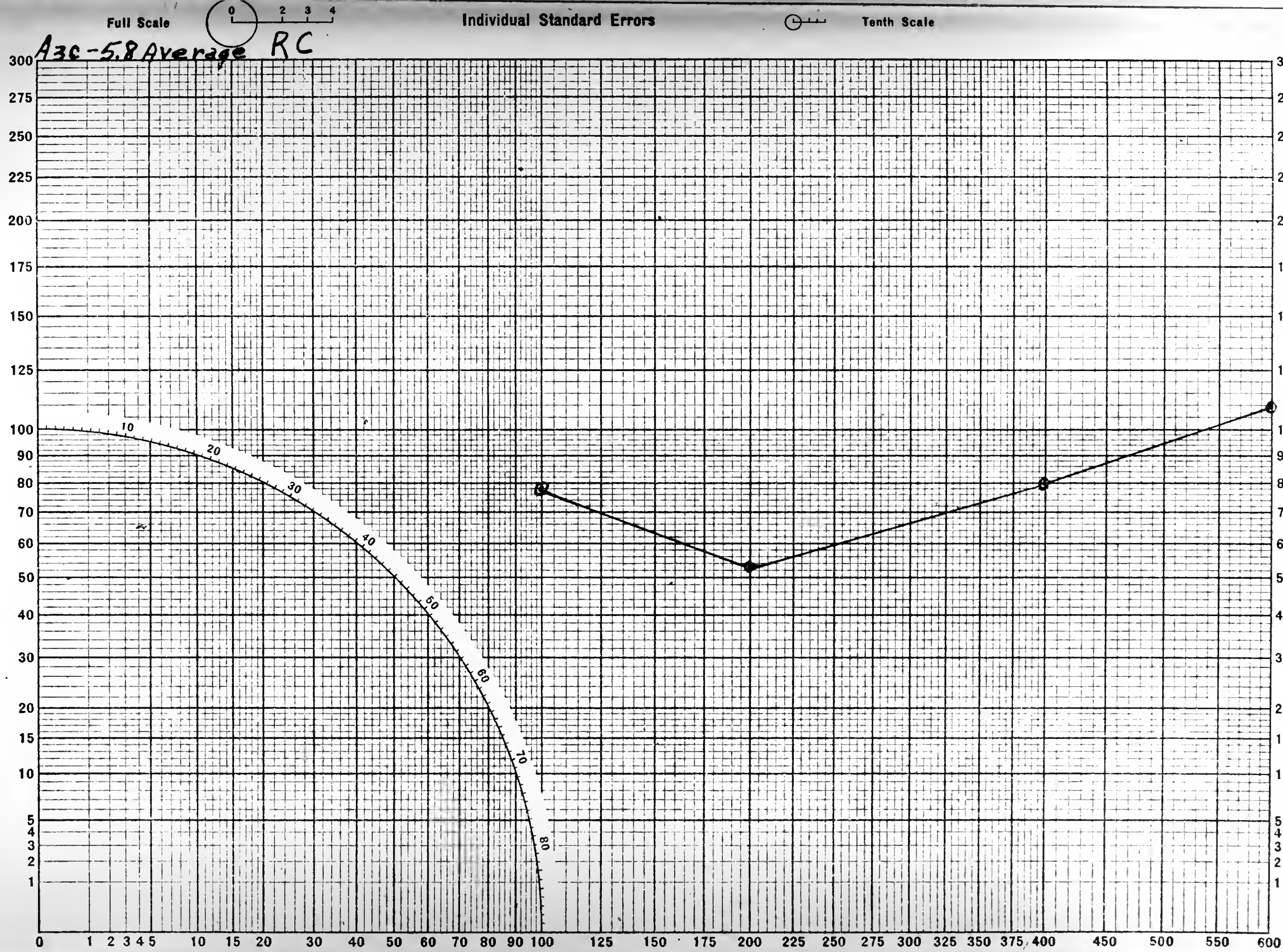
Full Scale | Individual Standard Errors | Tenth Scale

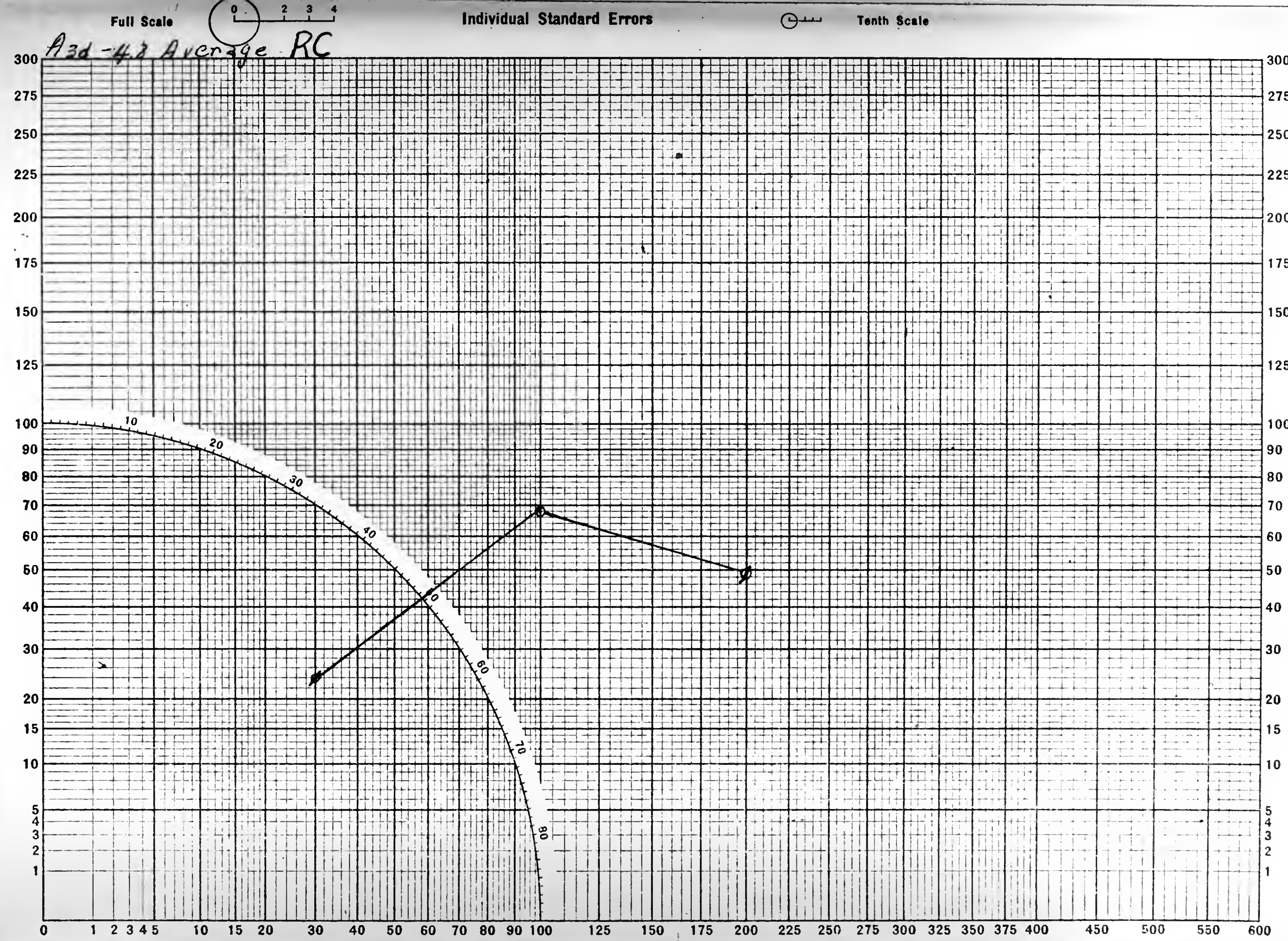
A3b-4.8 Average RC



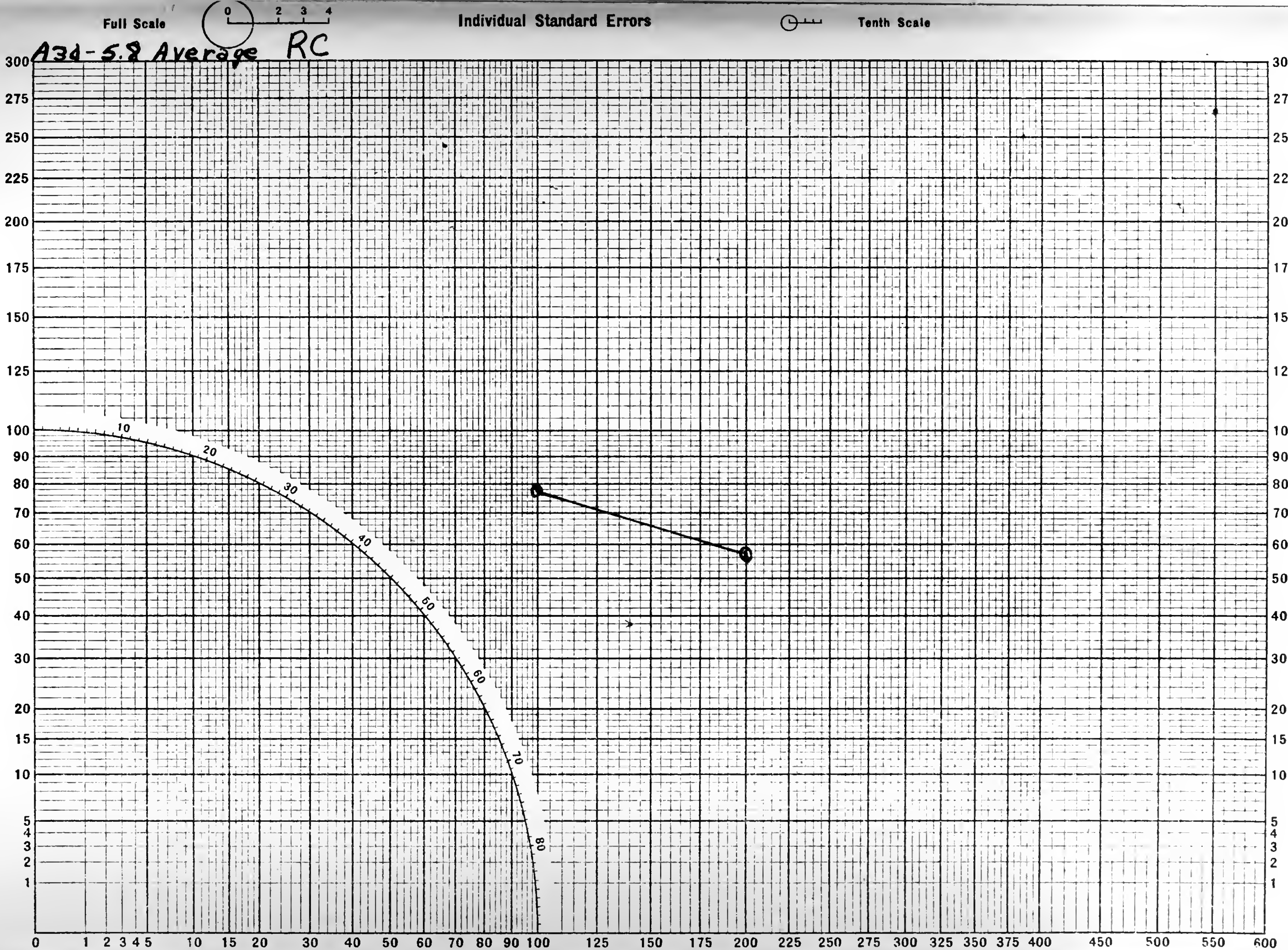
Full Scale
Individual Standard Errors
Tenth Scale
A3b-5.8 Average
RC


Full Scale
Individual Standard Errors
Tenth Scale
A3C - 4.8 Average RC

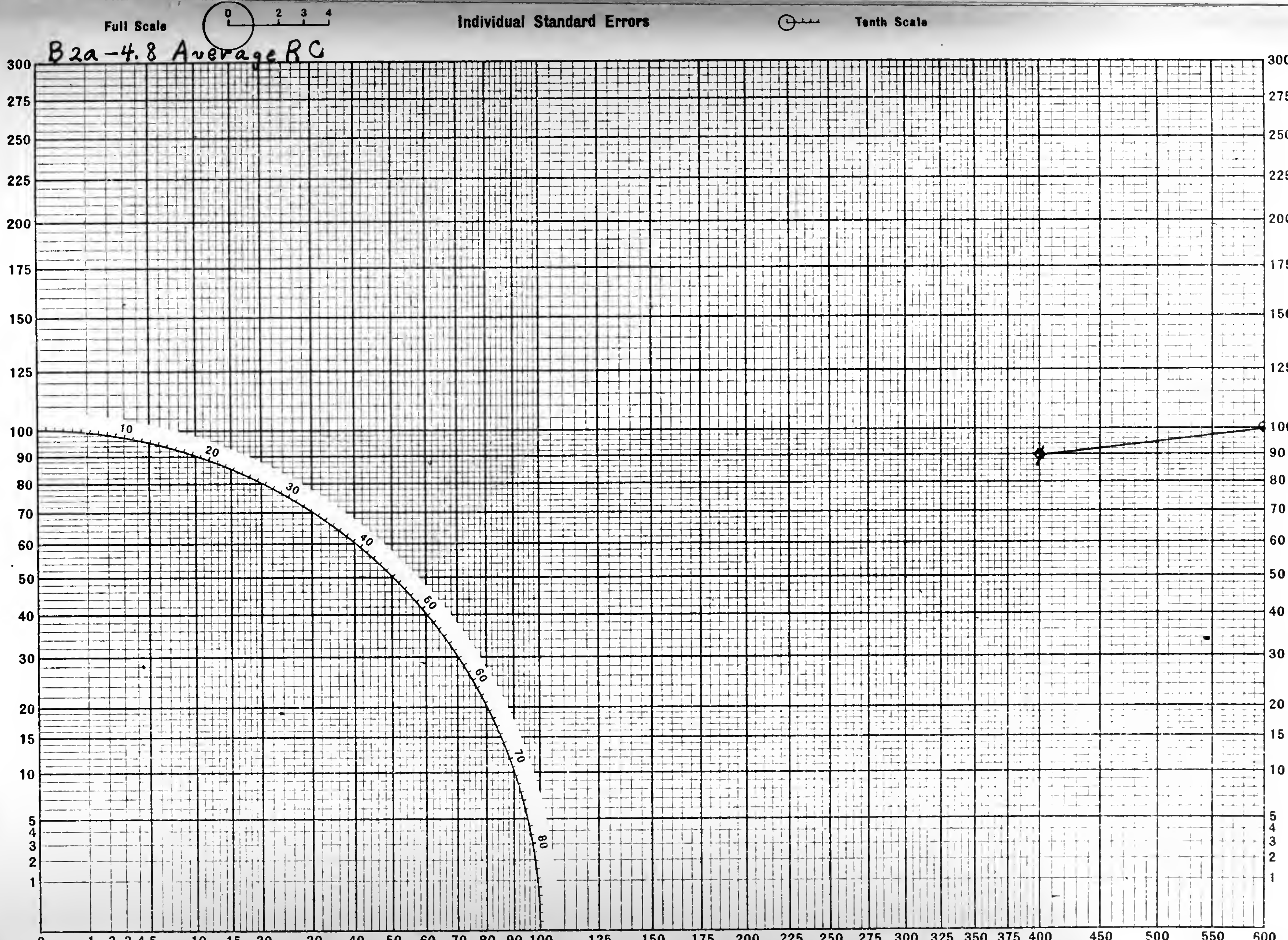

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A3c-5.8 Average RC



Full Scale
Individual Standard Errors
Tenth Scale
A3d-42 Average RC

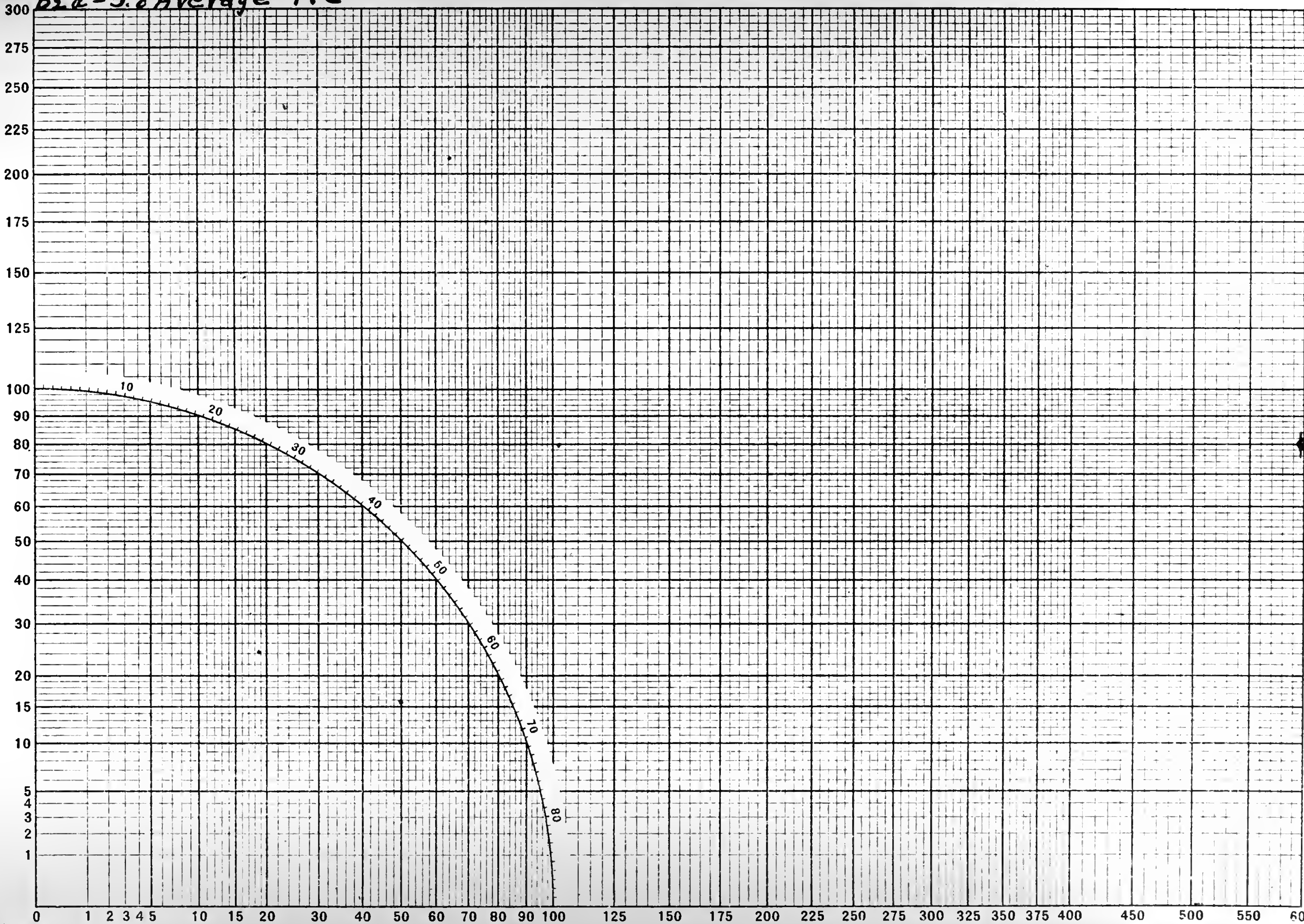


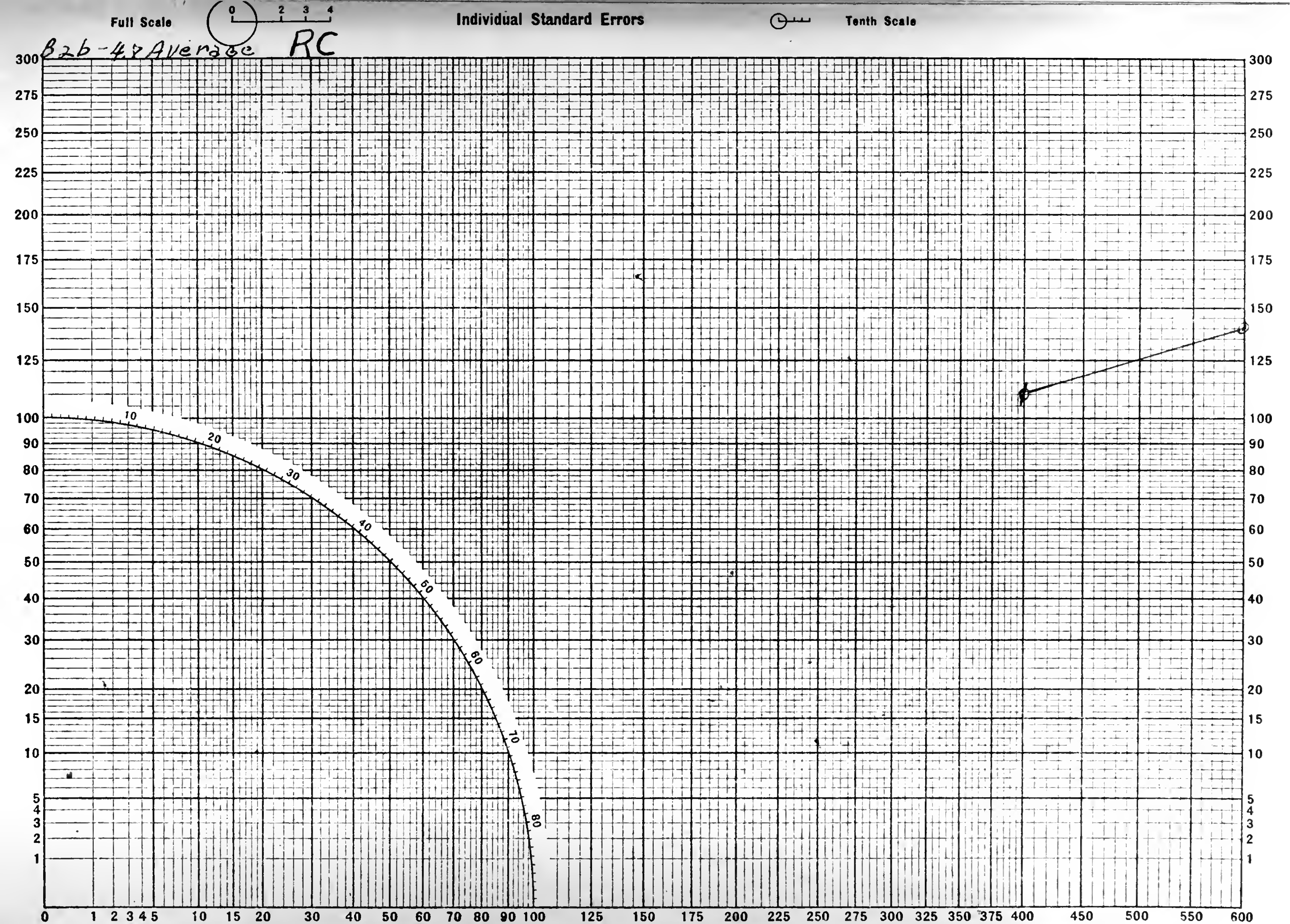
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A3d-5.8 Average
RC

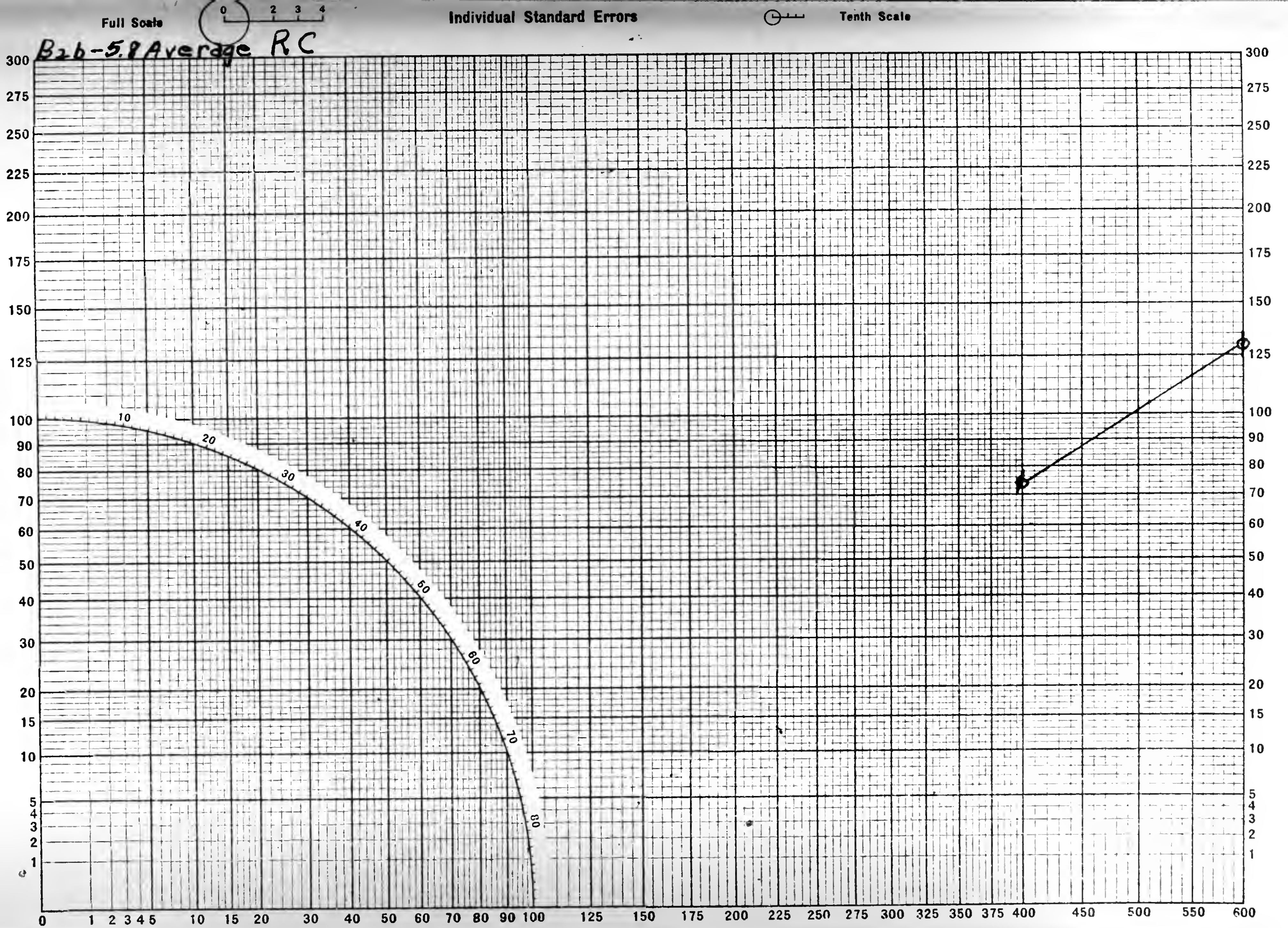

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B 2a -4.8 Average RC

Full Scale   Individual Standard Errors   Tenth Scale

B₂a-5.8 Average RC




Full Scale
Individual Standard Errors
Tenth Scale
B2b-47 Average
RC



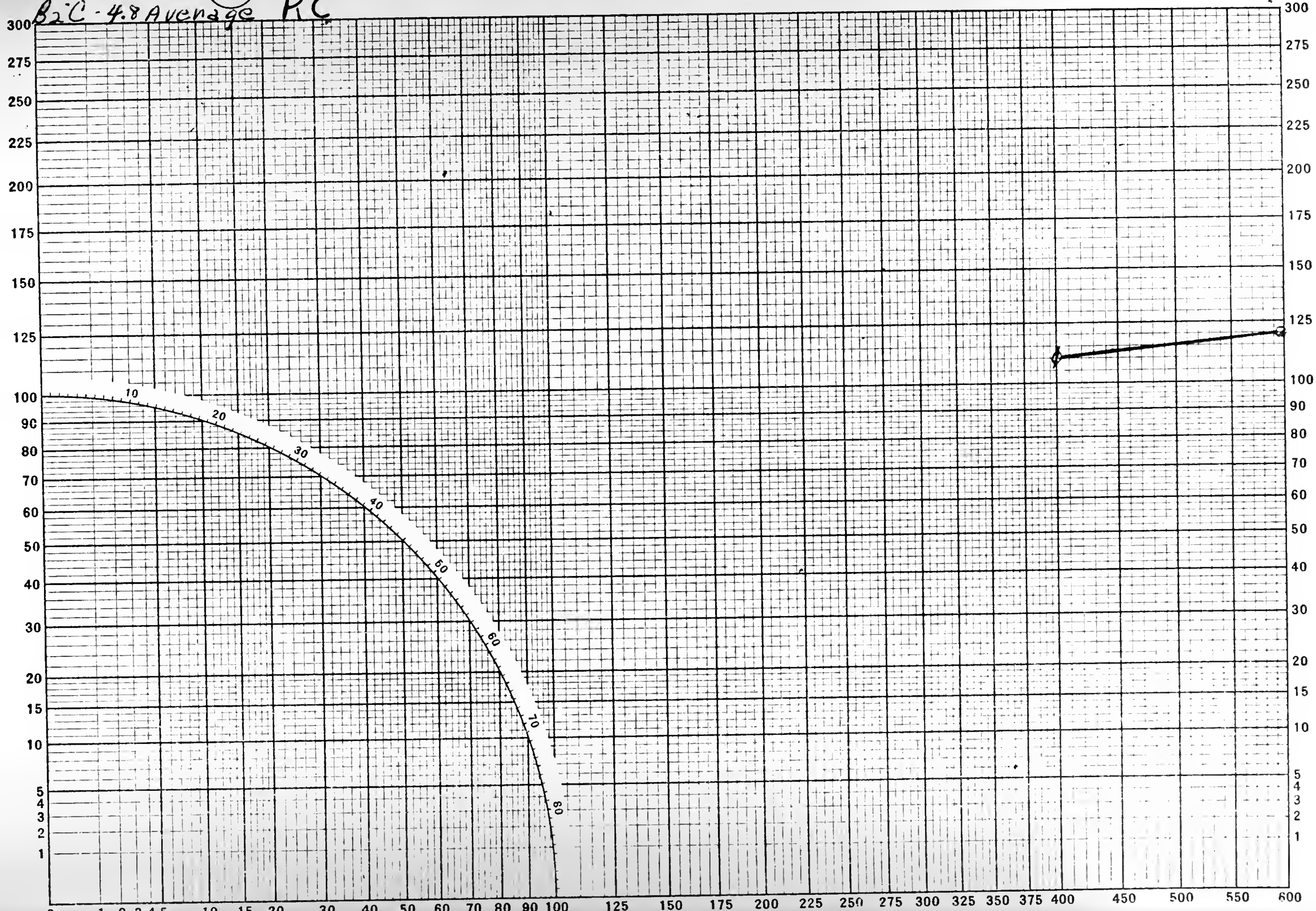
Full Scale
Individual Standard Errors
Tenth Scale
B2b-5.8 Average RC

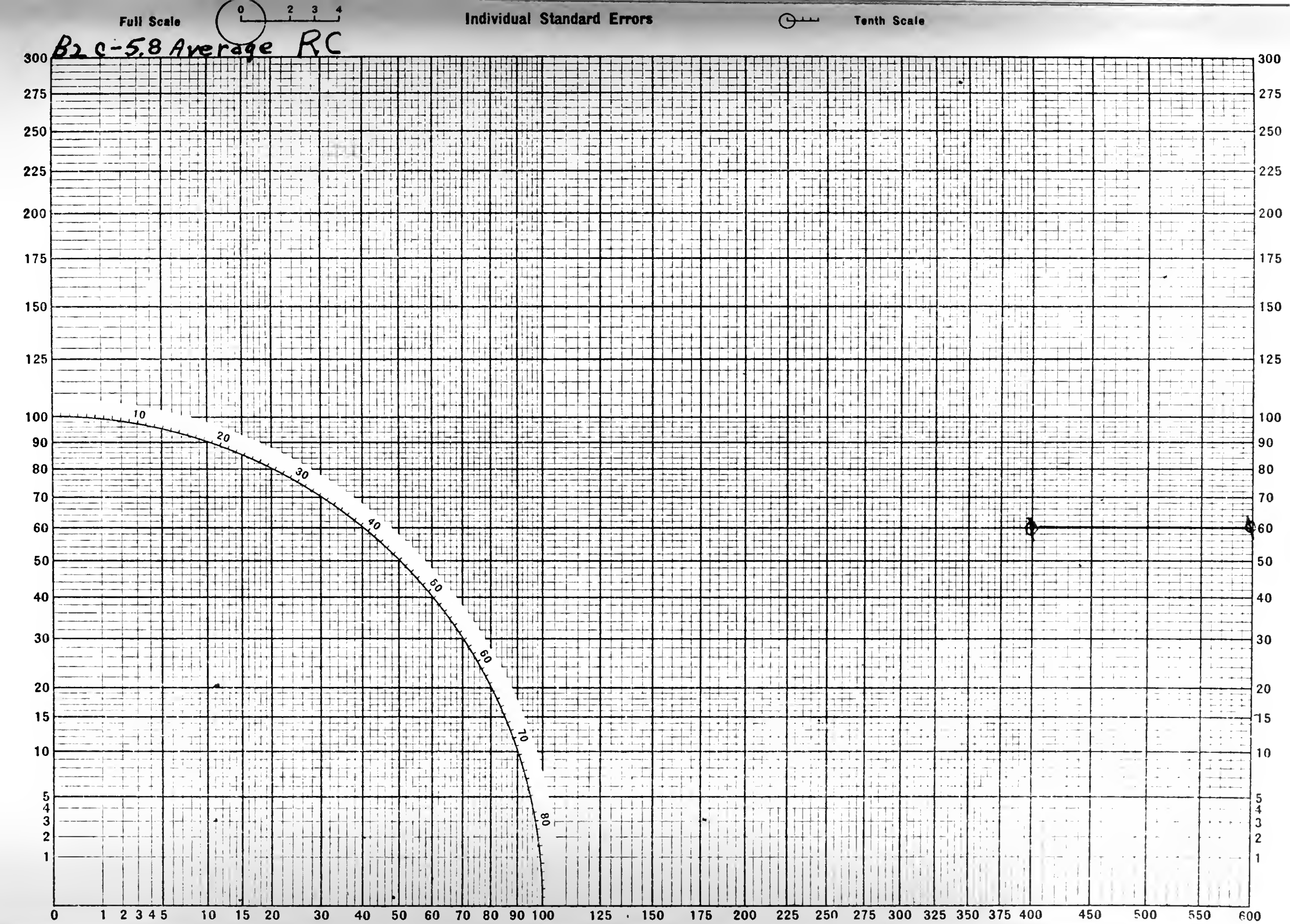
Full Scale

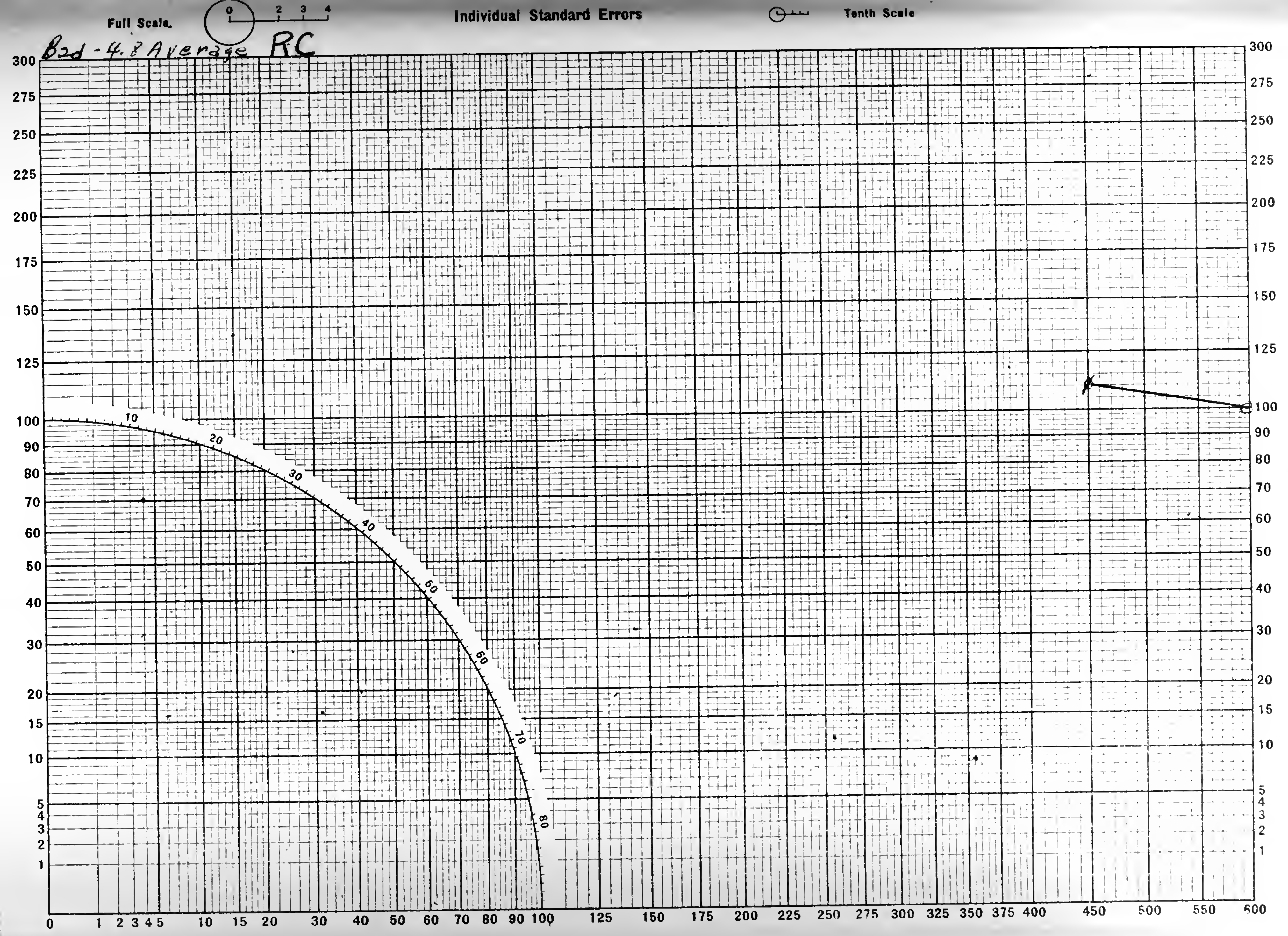
Individual Standard Errors

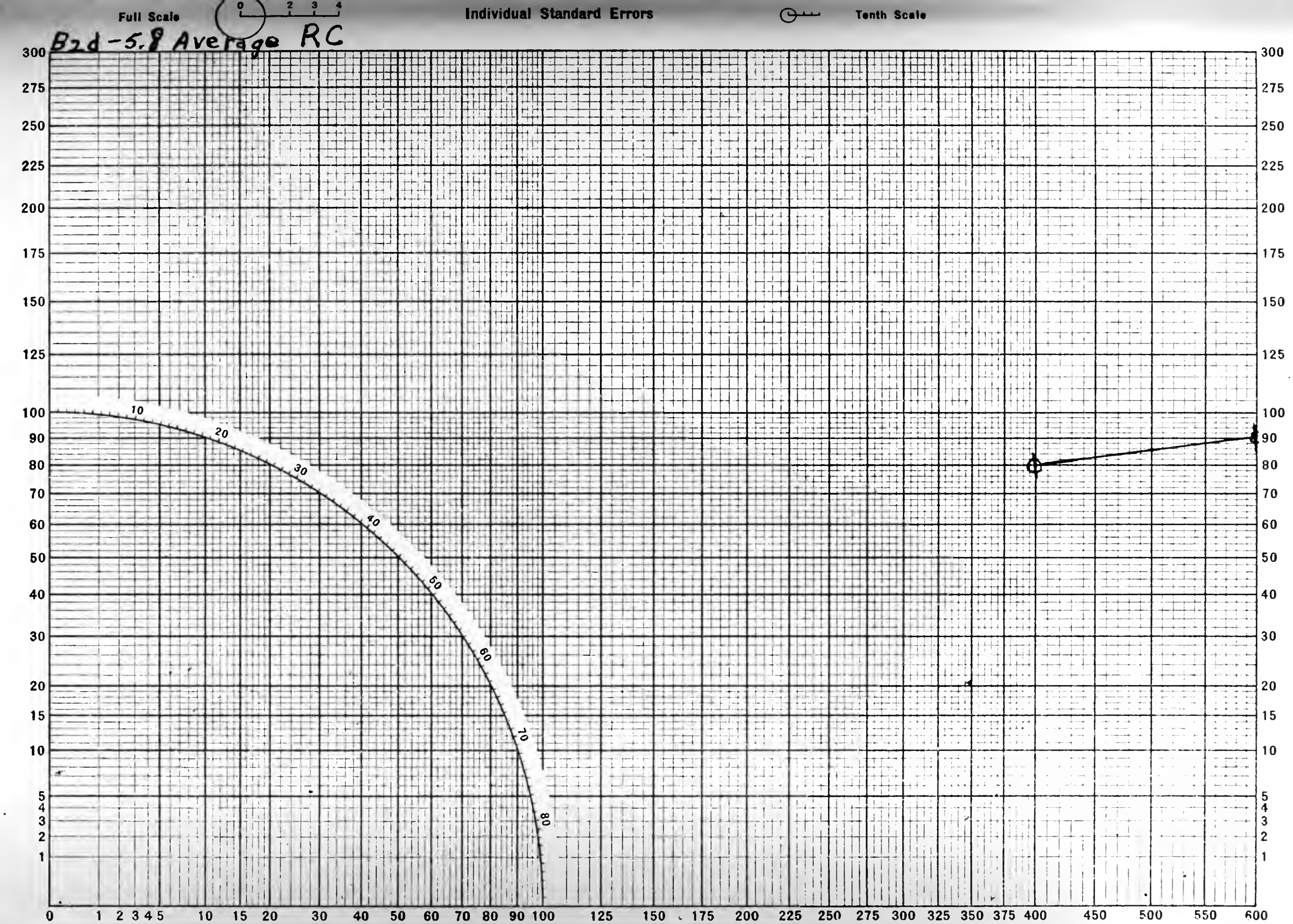
Tenth Scale

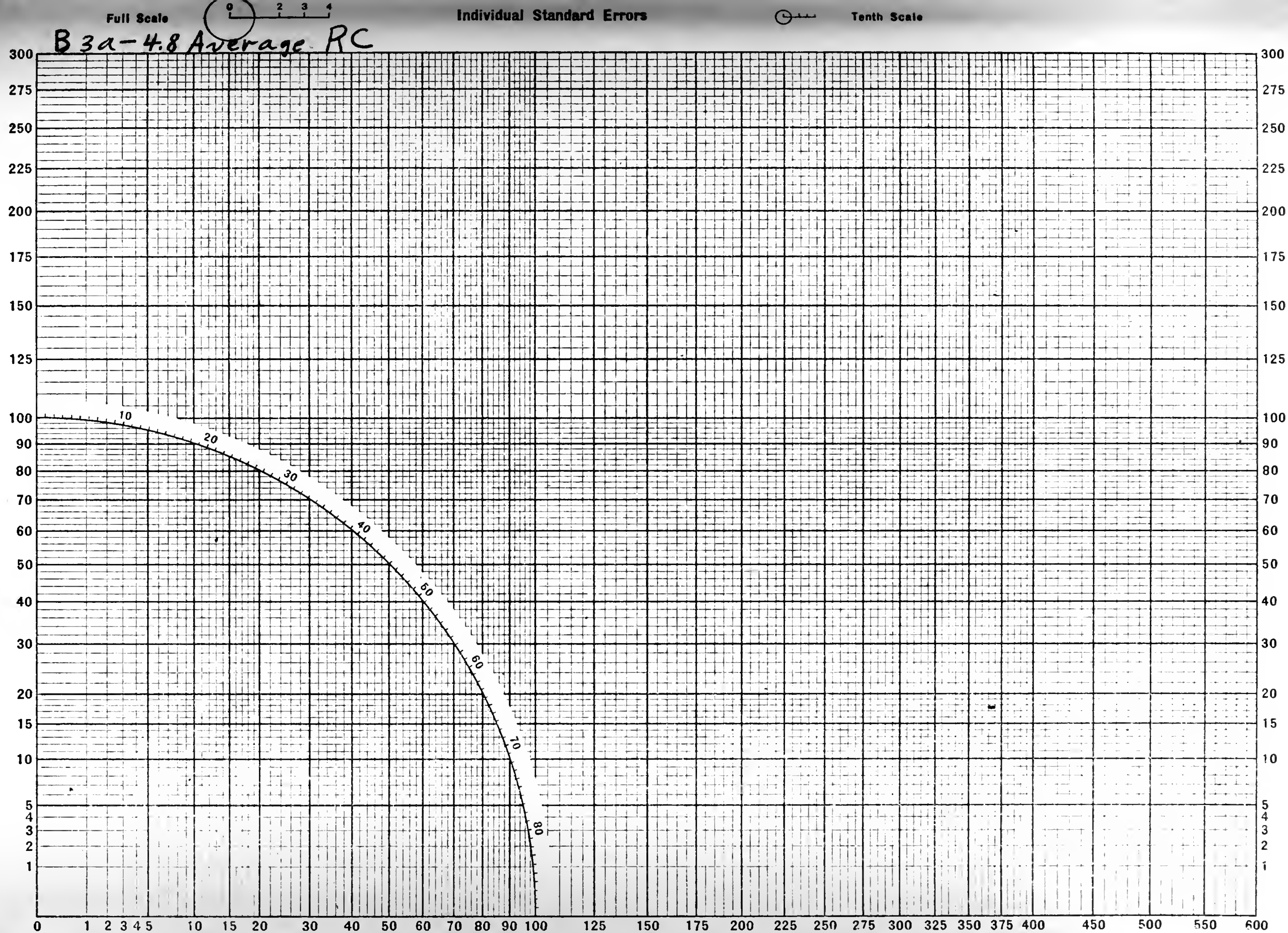
B_2C - 4.8 Average RC

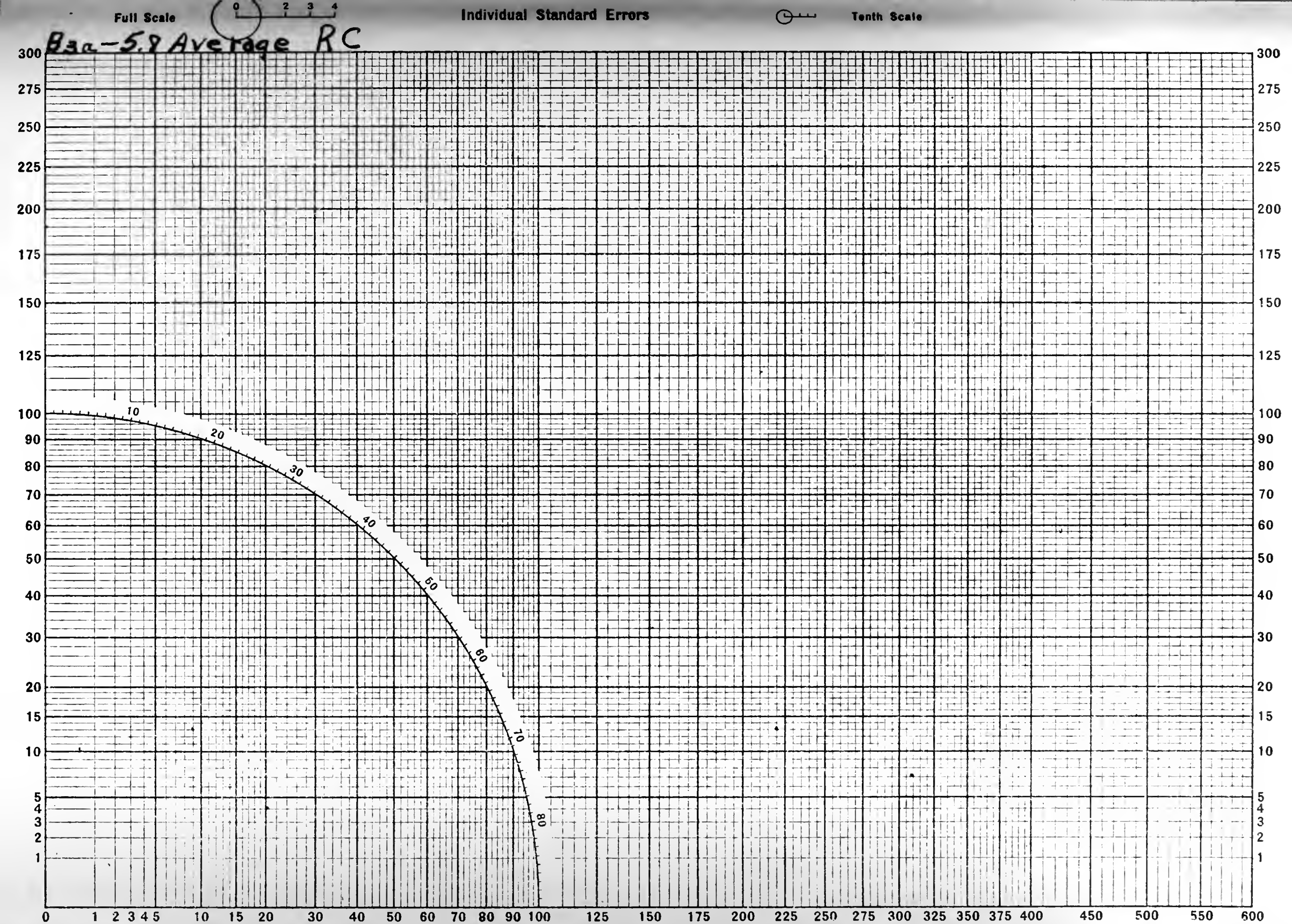


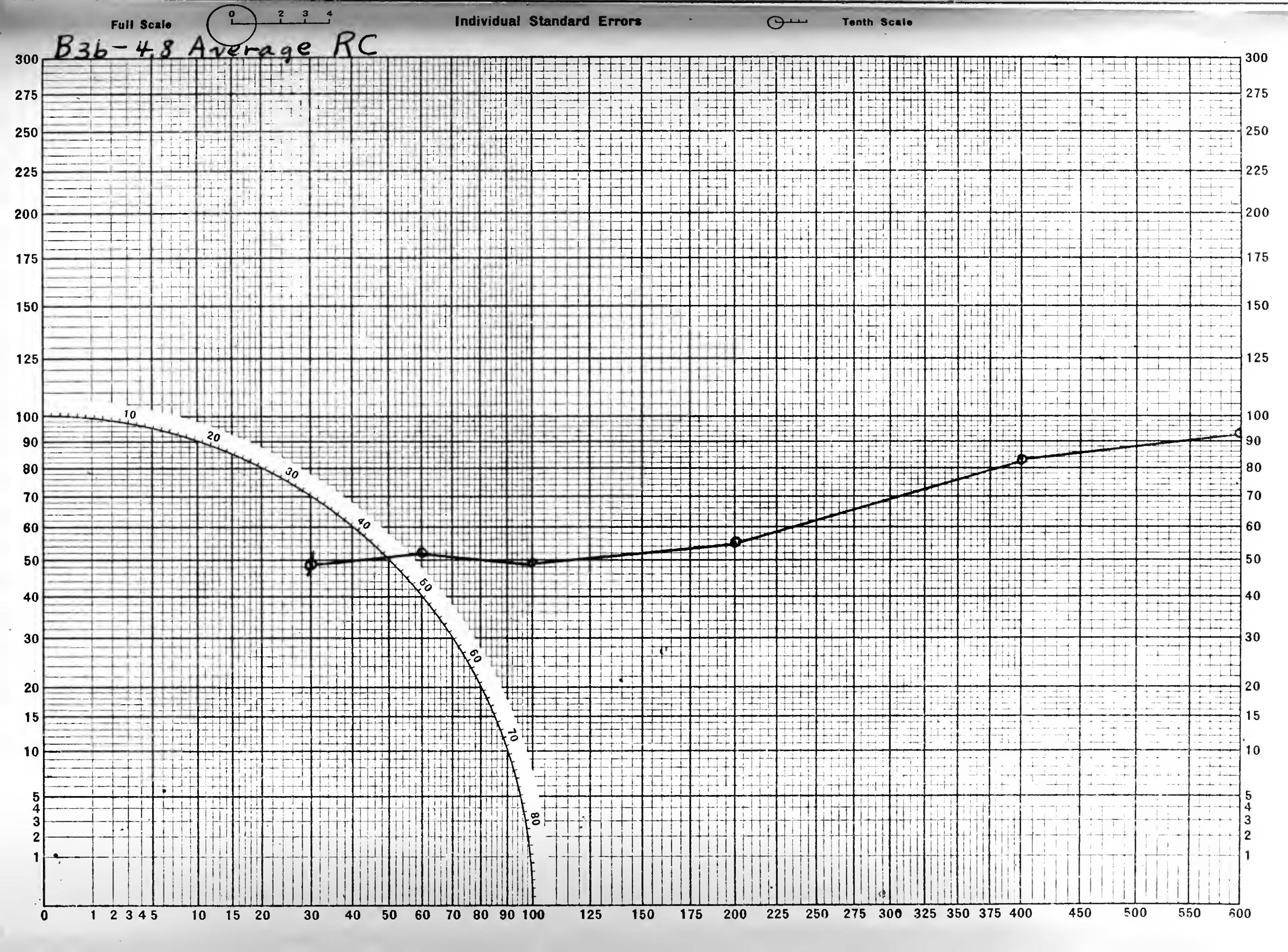

Full Scale
Individual Standard Errors
Tenth Scale
B2 c-5.8 Average RC

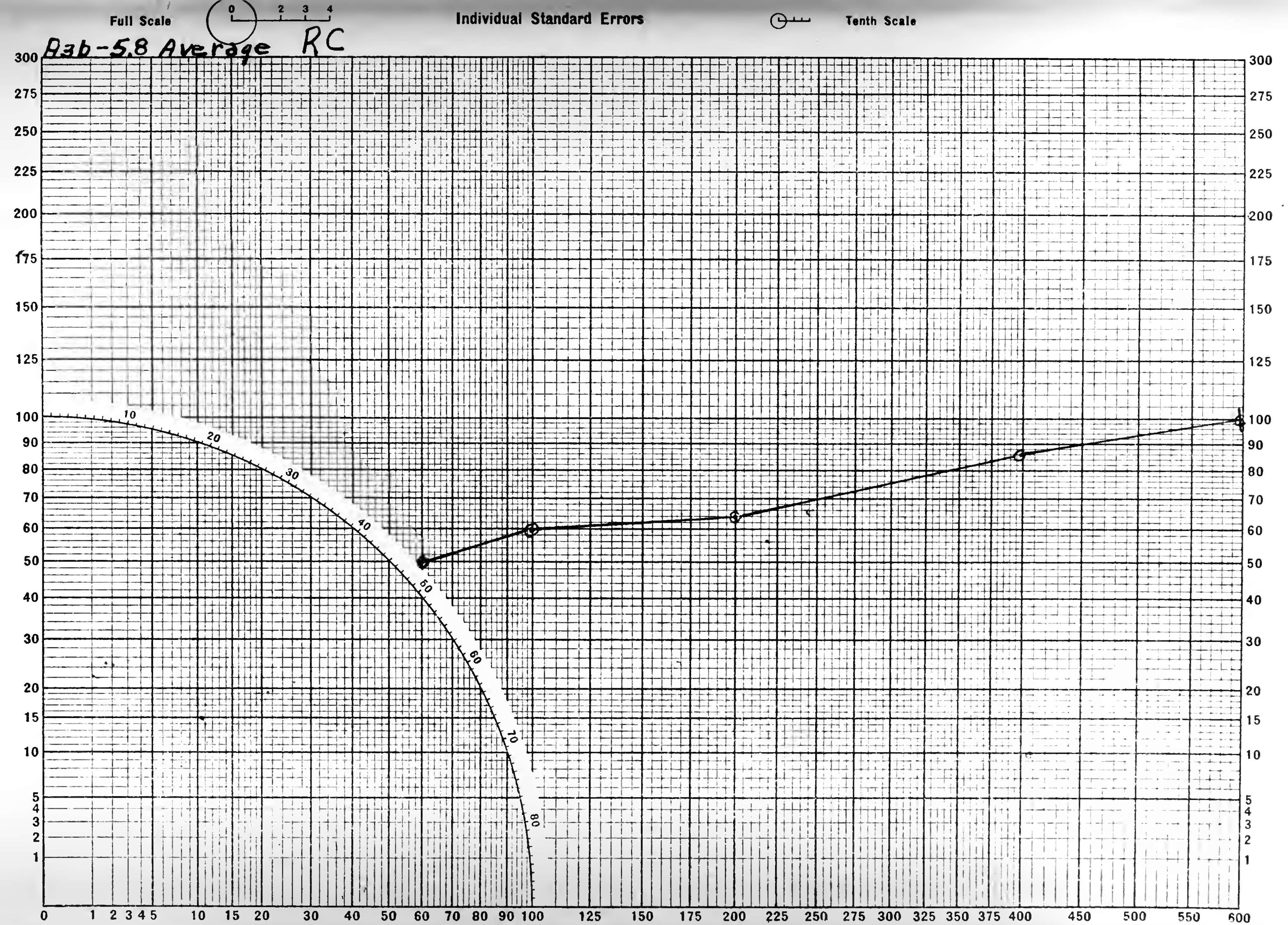

Full Scale.
0 2 3 4
Individual Standard Errors
Tenth Scale
82d - 4.8 Average RC


Full Scale
Individual Standard Errors
Tenth Scale
B2d-5.8 Average RC


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B 3a-4.8 Average RC


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B3a-5.8 Average RC
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

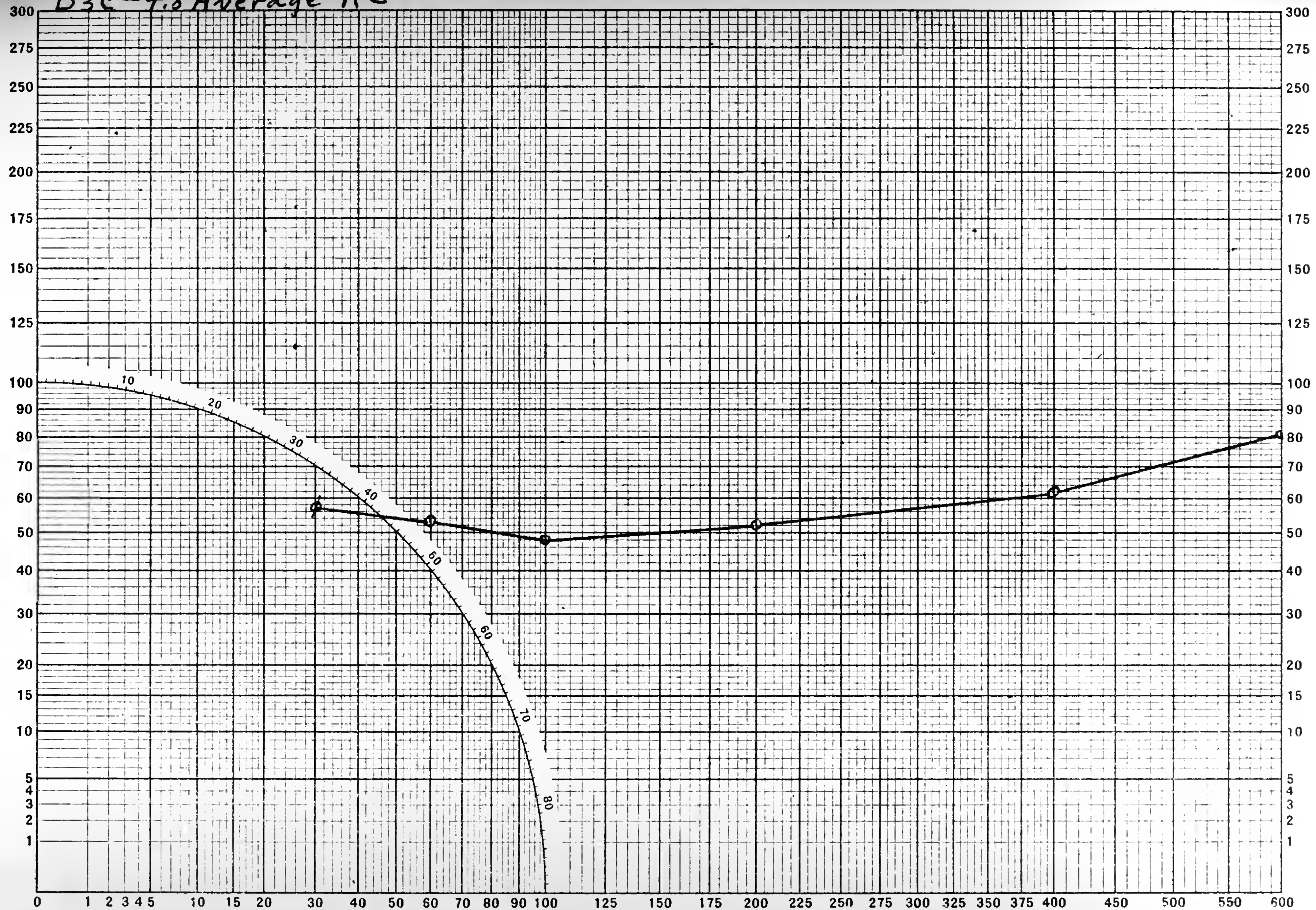

Full Scale
Individual Standard Errors
Tenth Scale
B3b-4.8 Average RC



Full Scale
Individual Standard Errors
Tenth Scale
A3b-5.8 Average RC

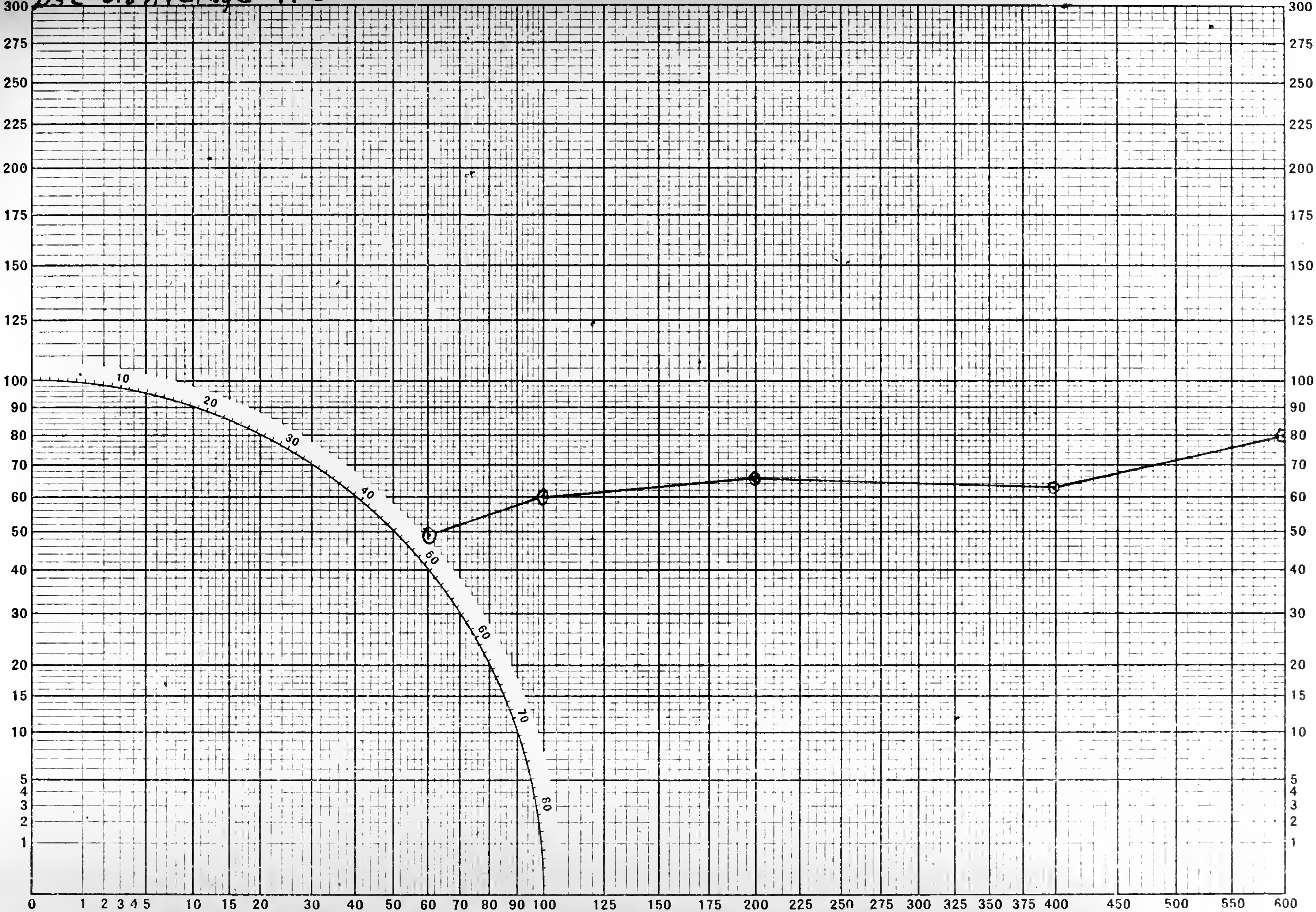
Full Scale   Individual Standard Errors   Tenth Scale

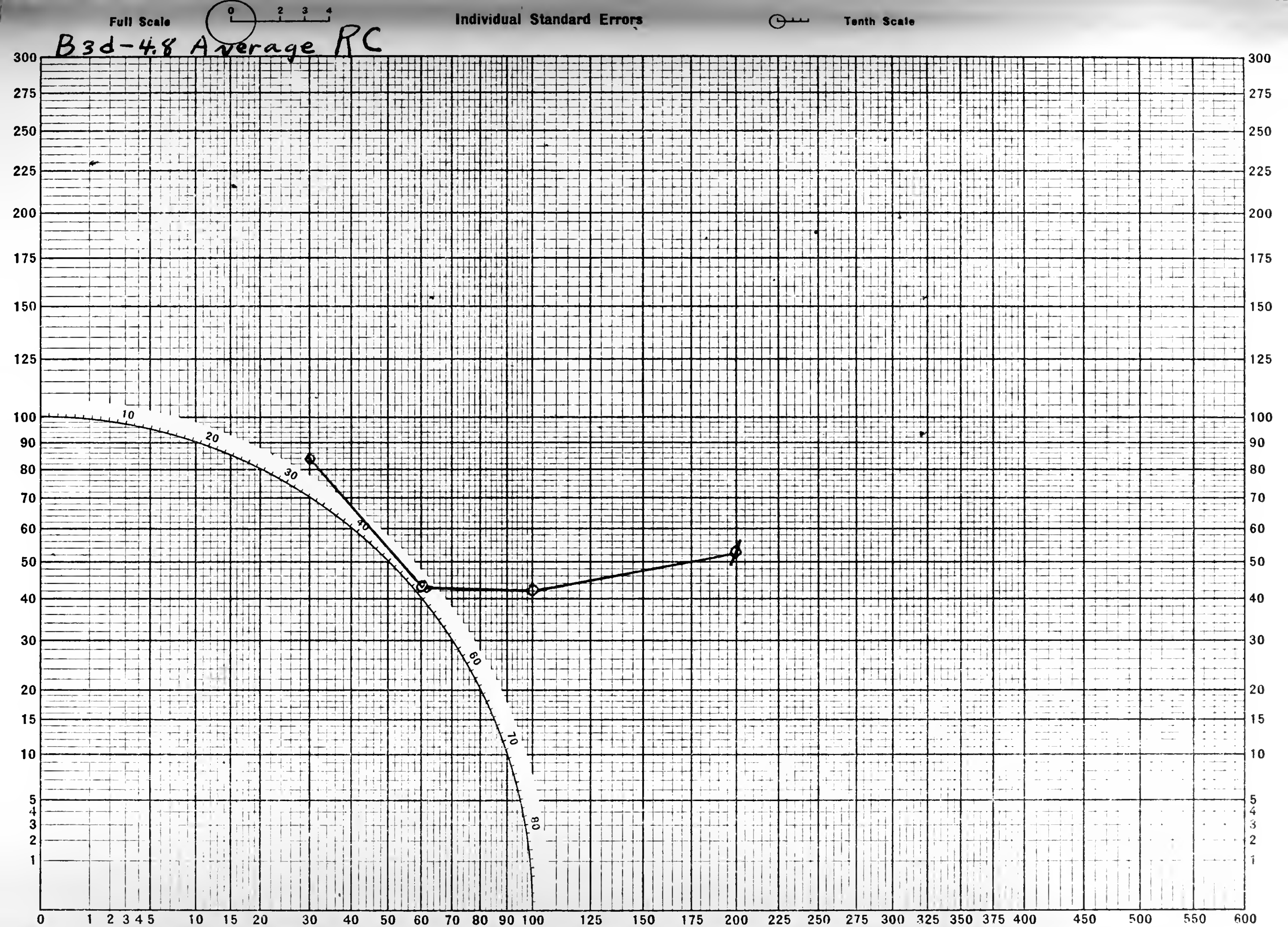
B3c-4.8 Average RC



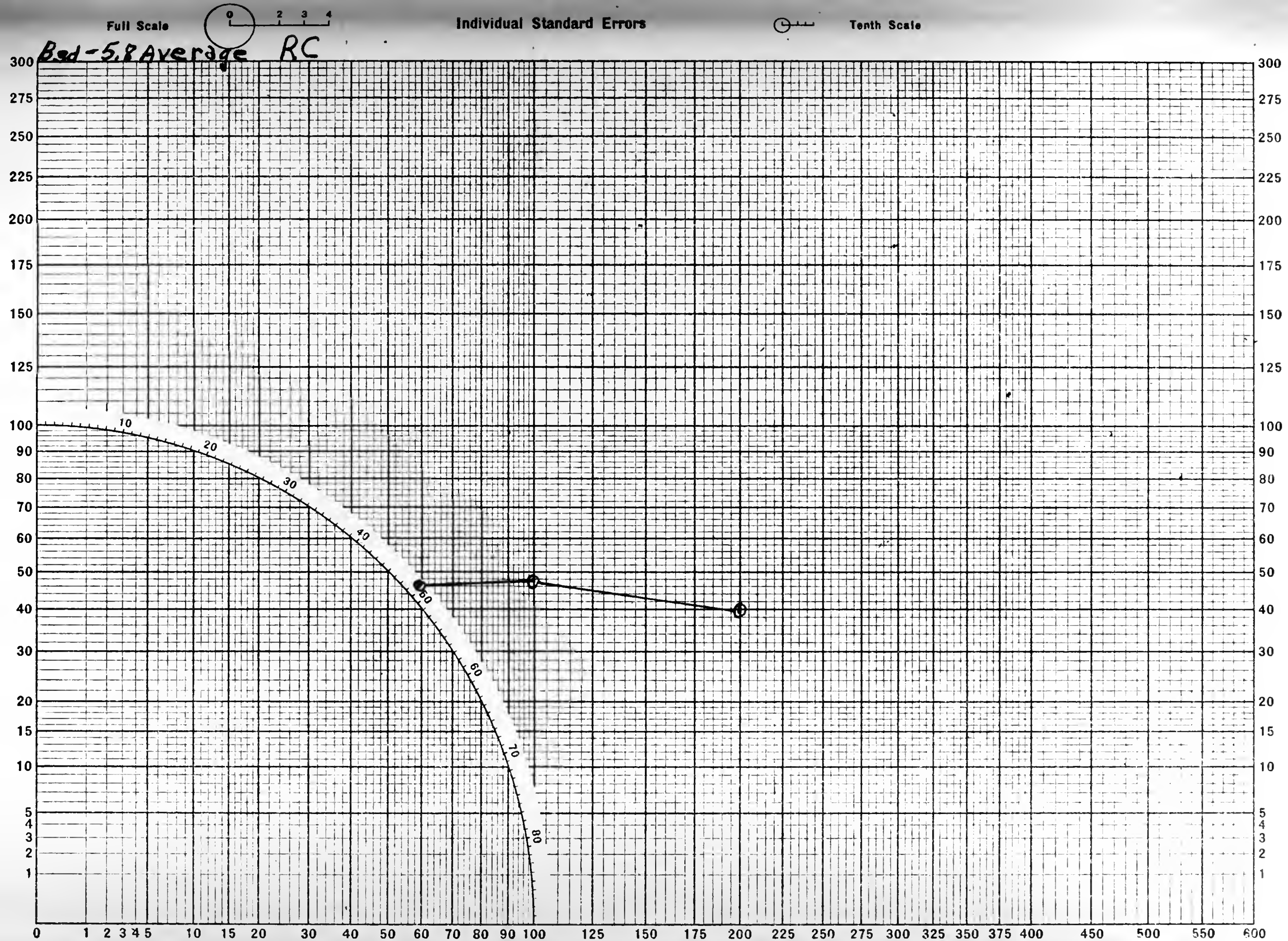
Full Scale Individual Standard Errors Tenth Scale

B3c-5.8 Average RC





Full Scale
Individual Standard Errors
Tenth Scale
B3d-4.8 Average RC


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
Bsd-5.8 Average RC

Full Scale Individual Standard Errors Tenth Scale

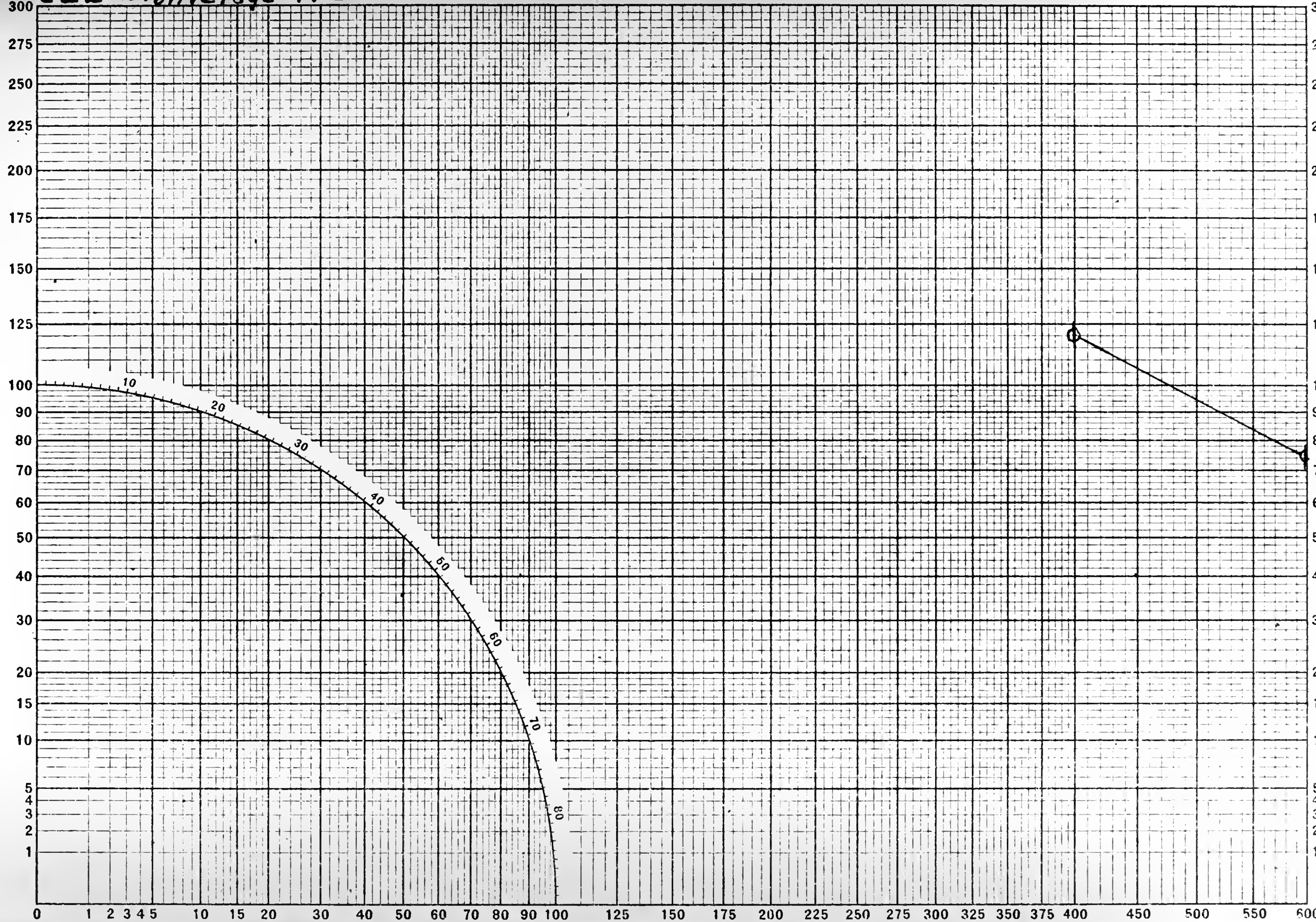
C2a - 4.8 Average RC

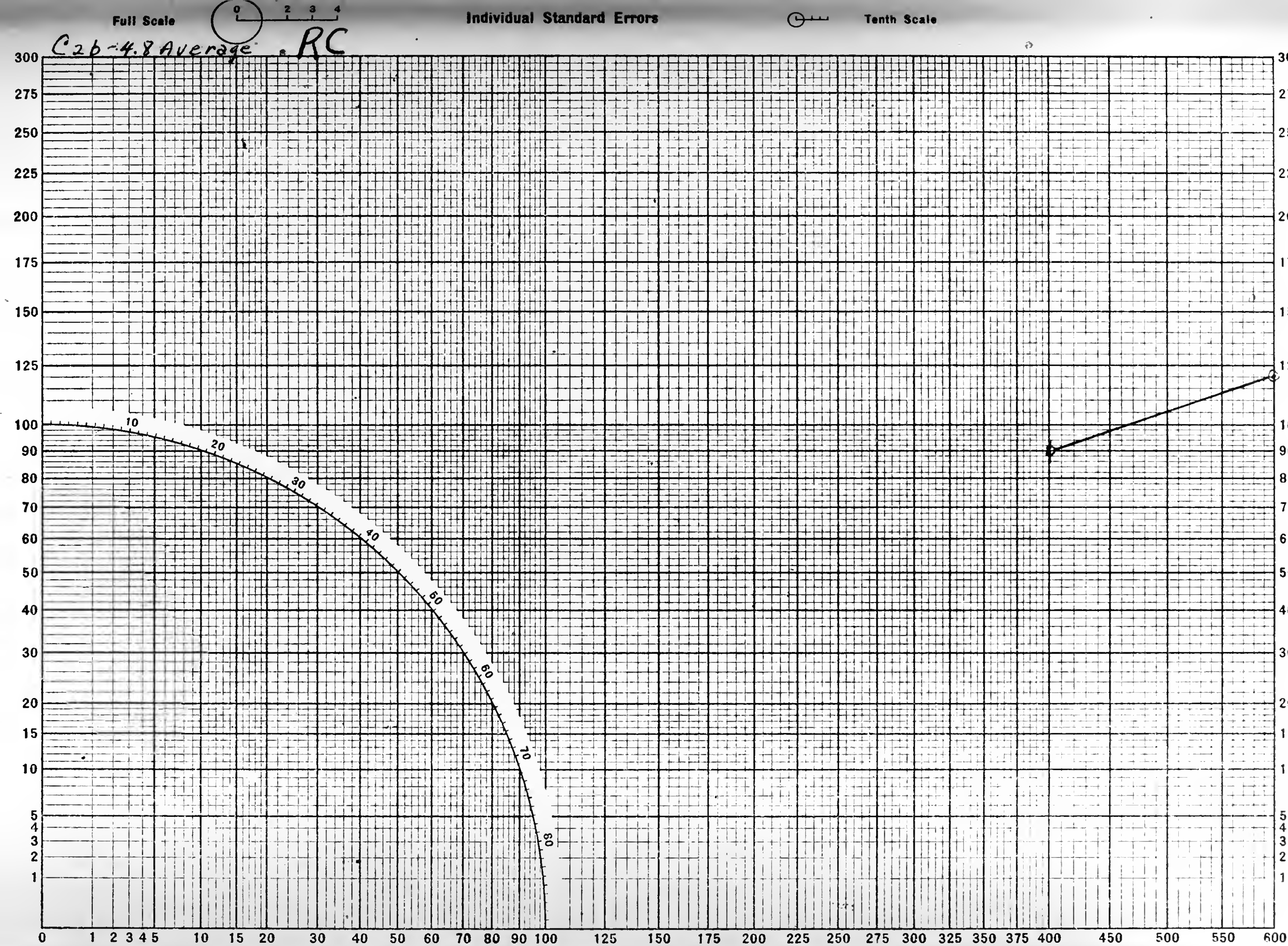
Full Scale

Individual Standard Errors

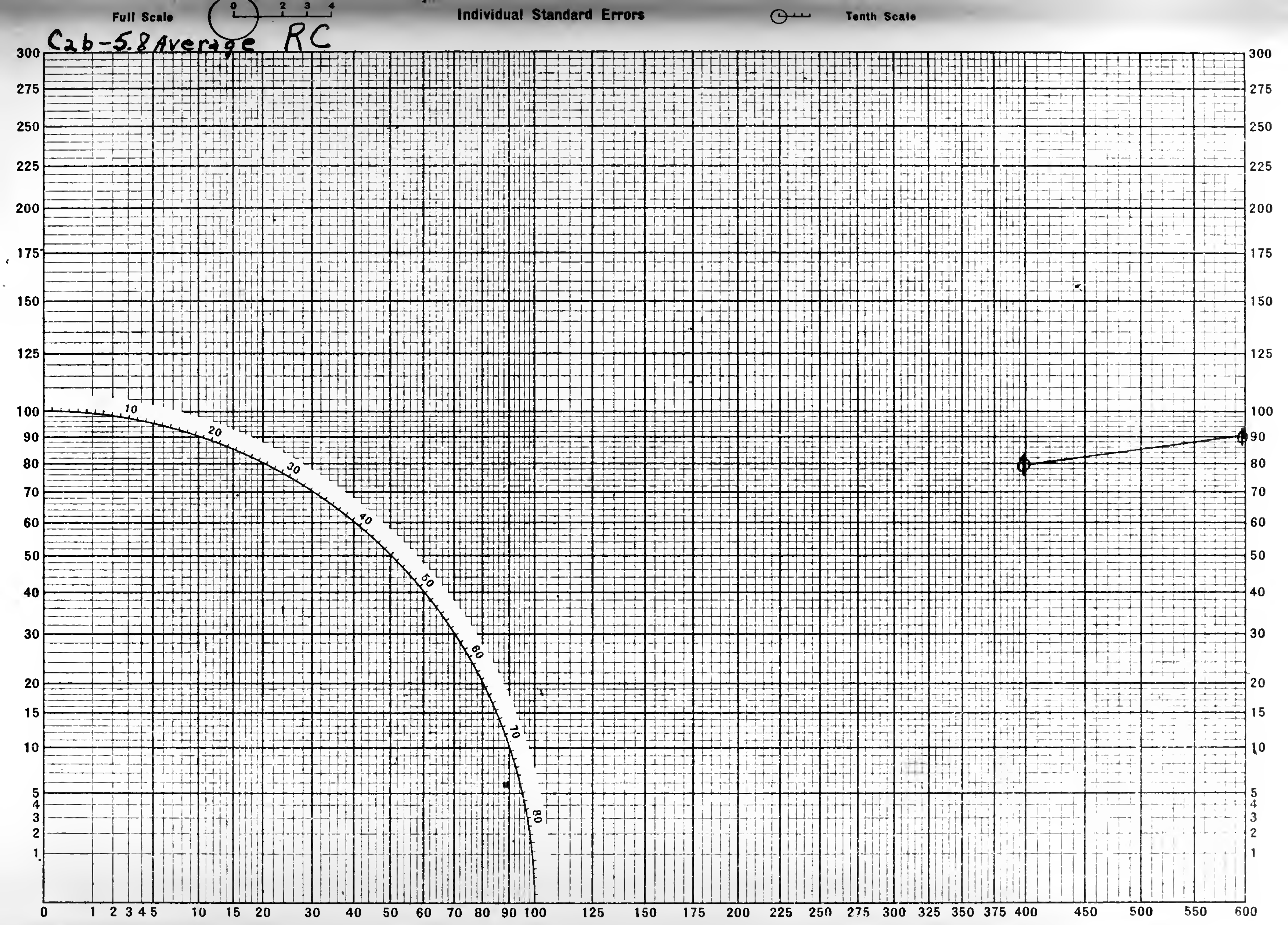
Tenth Scale

C2a -5.8 Average RC





Full Scale
Individual Standard Errors
Tenth Scale
C2b-4.8 Average
RC

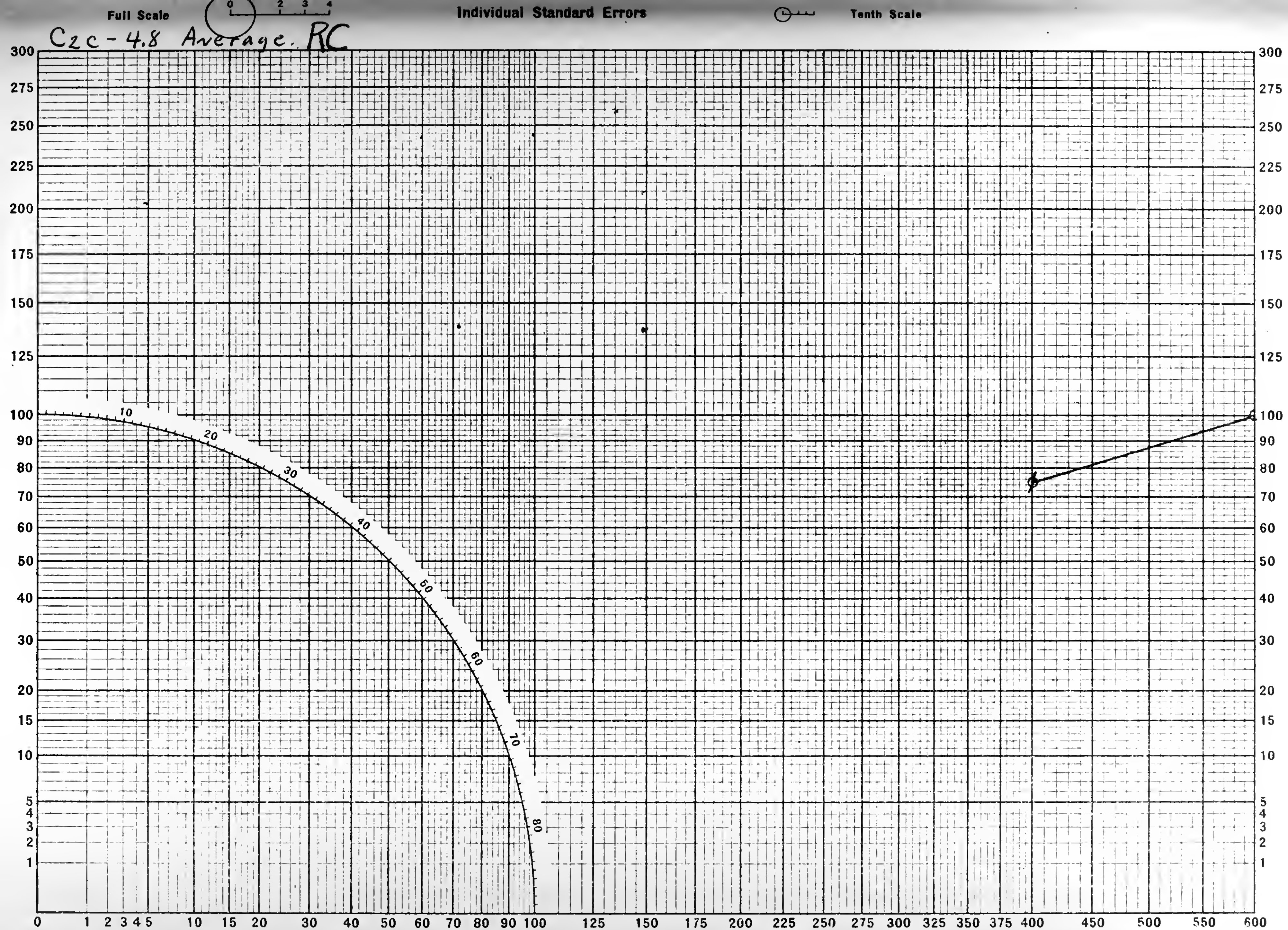

Full Scale
Individual Standard Errors
Tenth Scale
C2b-5.8 Average RC

Full Scale

Individual Standard Errors

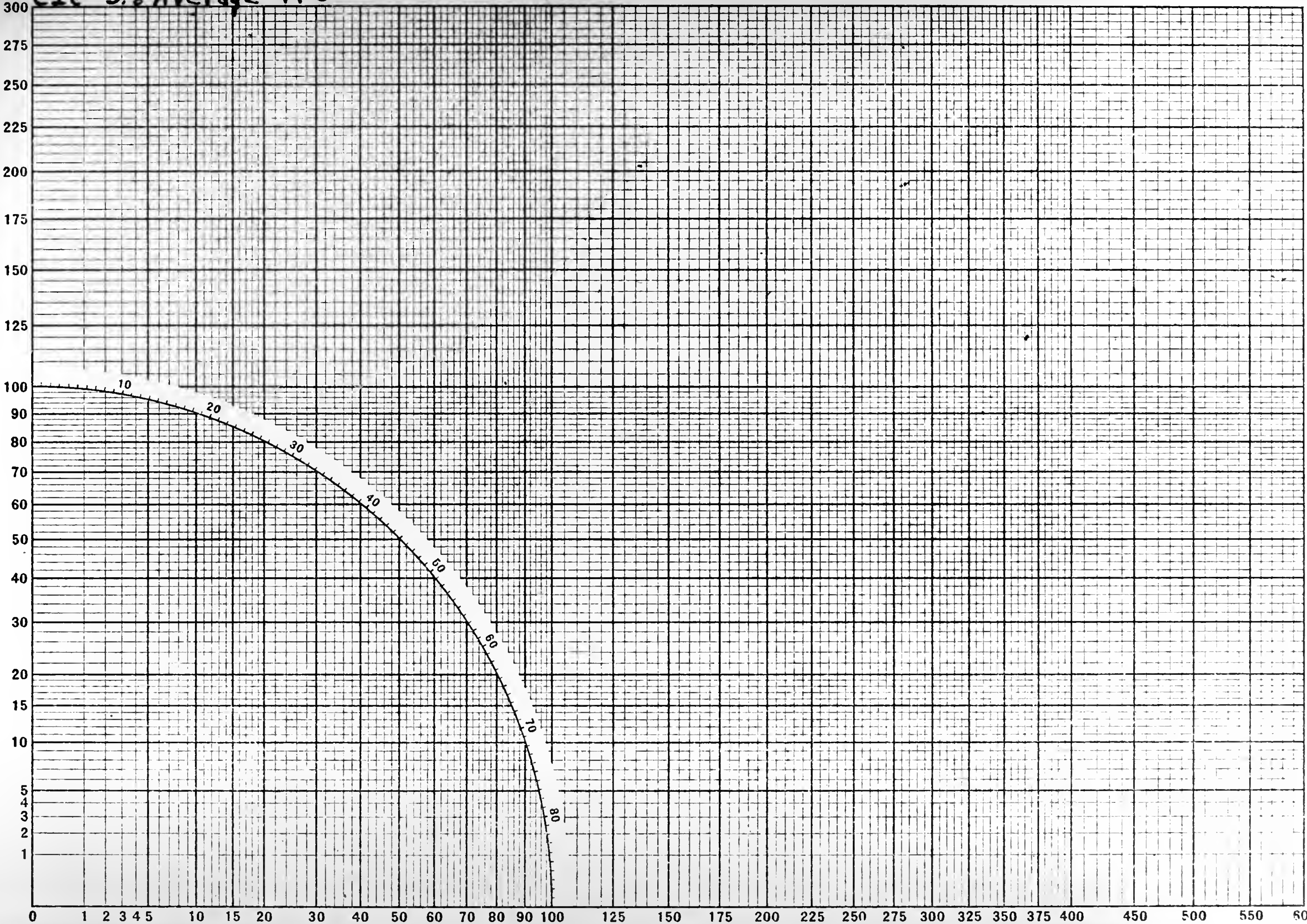
Tenth Scale

C2C - 4.8 Average. RC



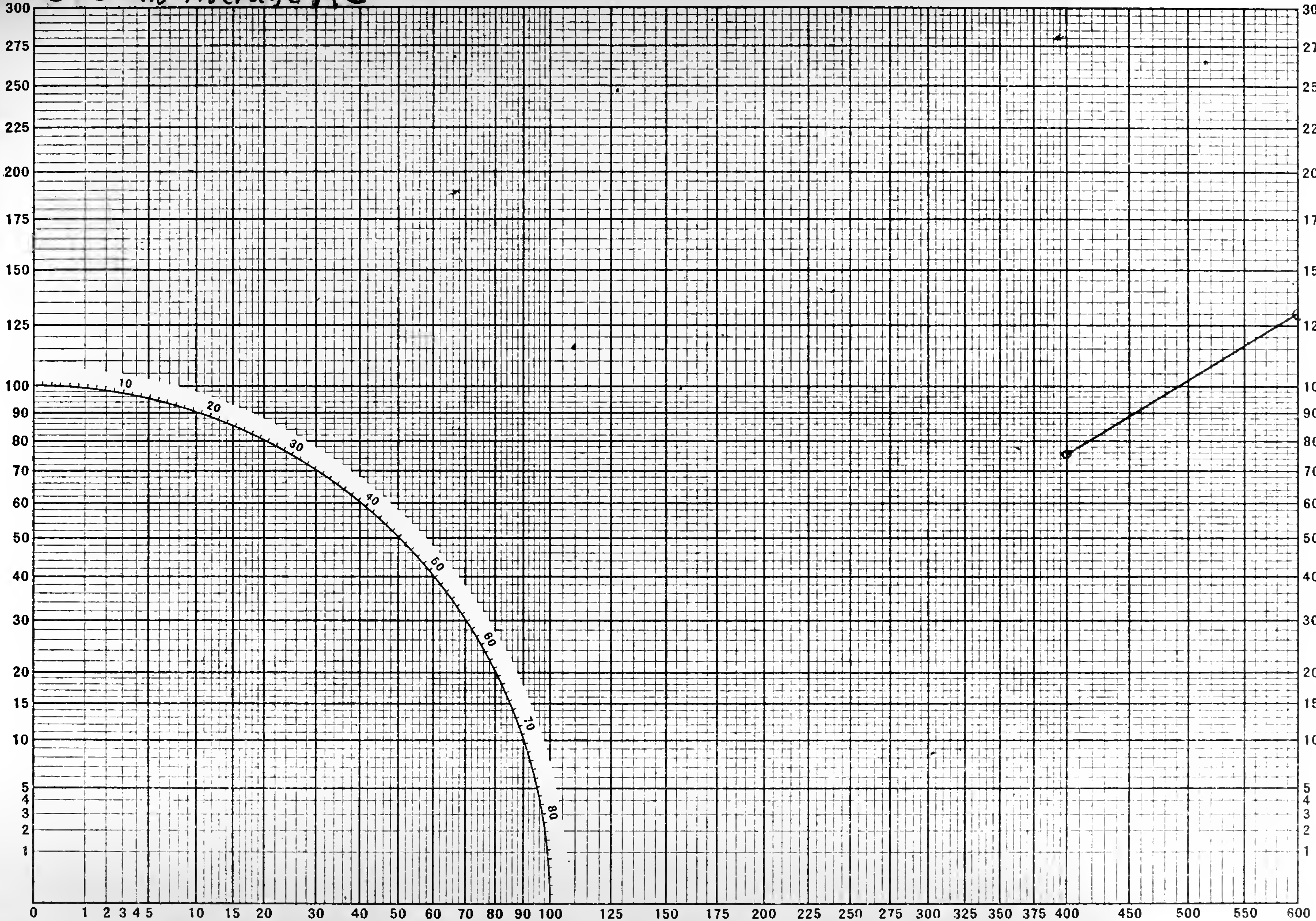
Full Scale Individual Standard Errors Tenth Scale

C2c -5.8 Average RC



Full Scale Individual Standard Errors Tenth Scale

C2d-4.8 Average RC

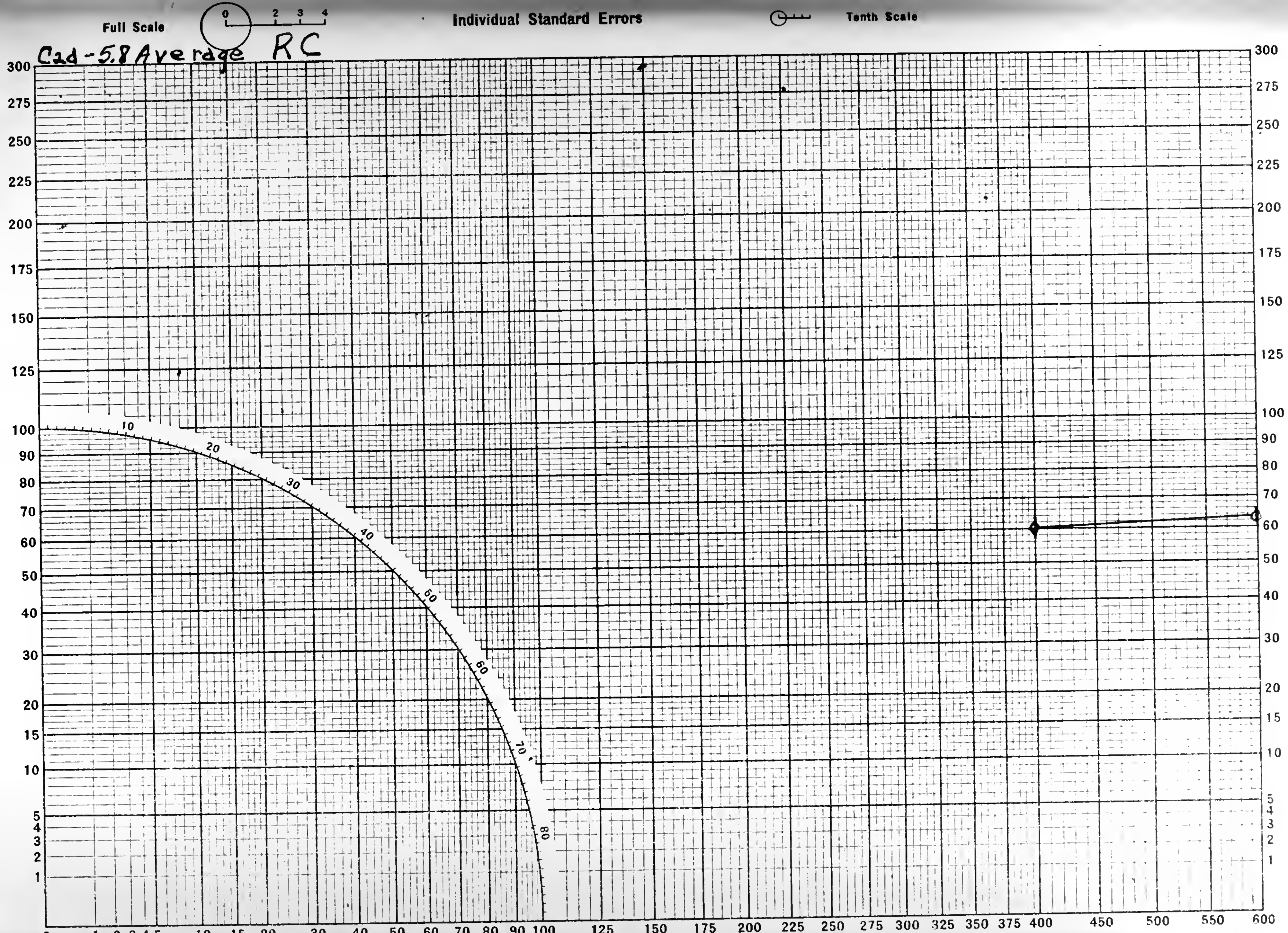


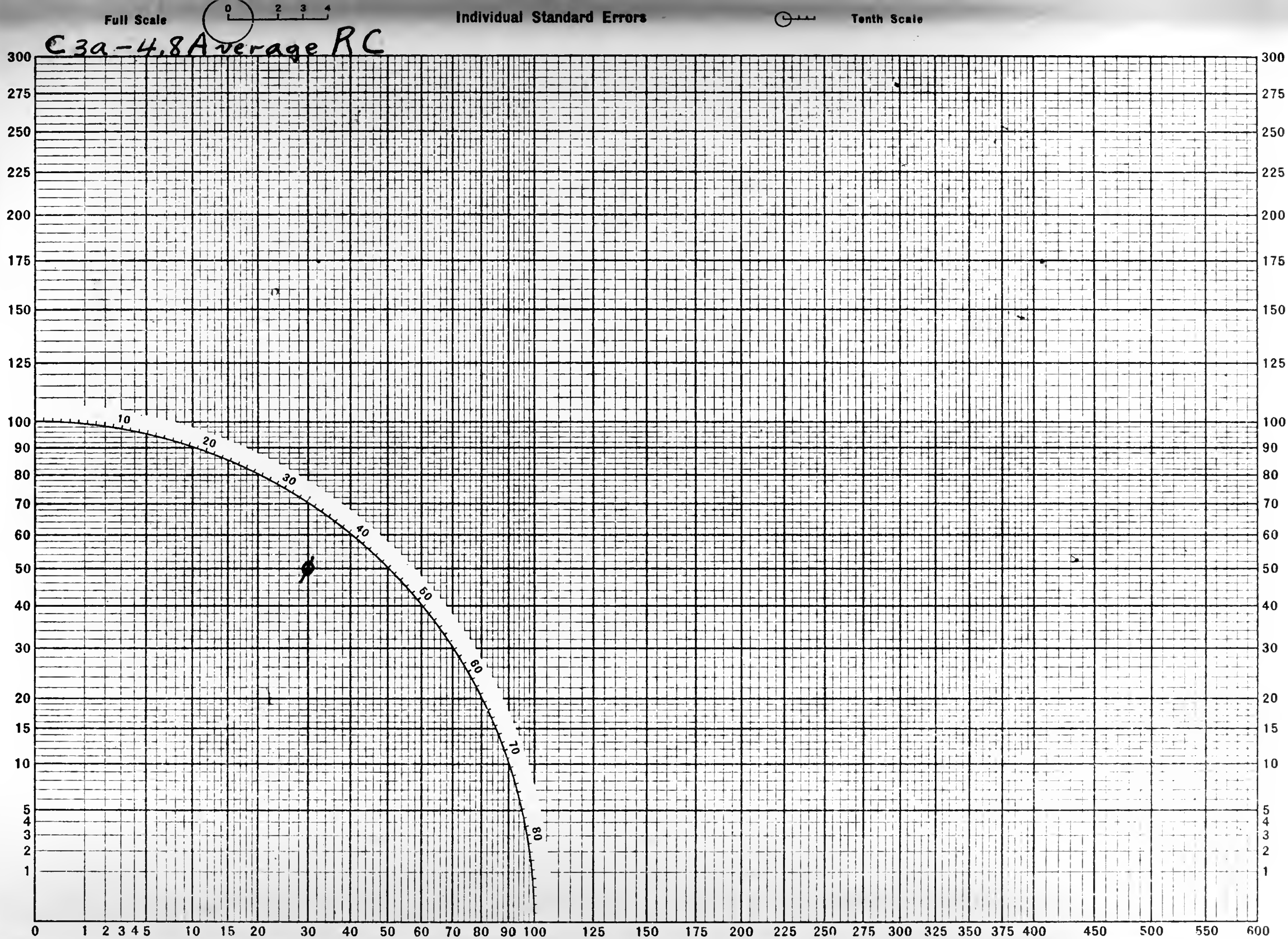
Full Scale

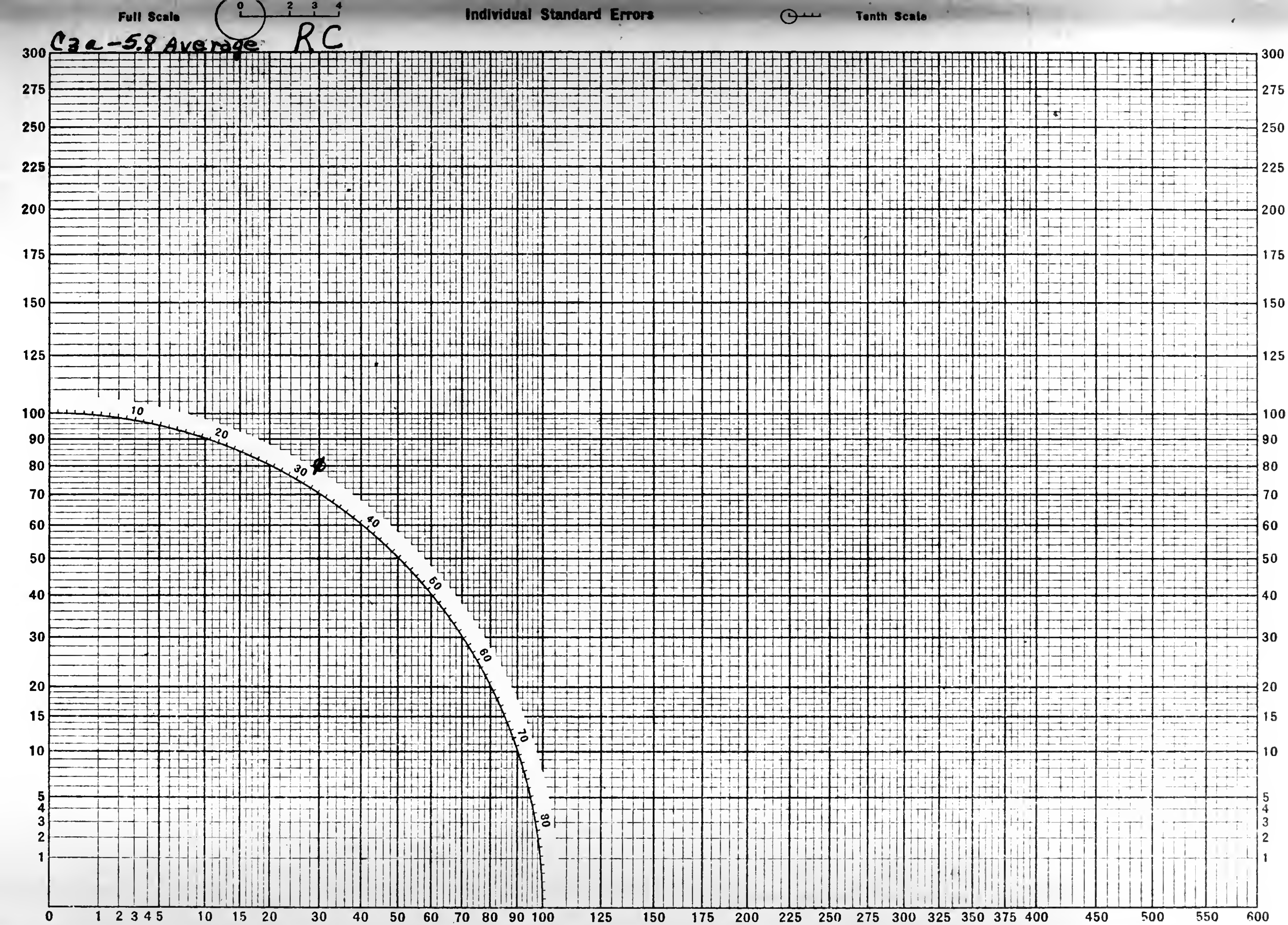
Individual Standard Errors

Tenth Scale

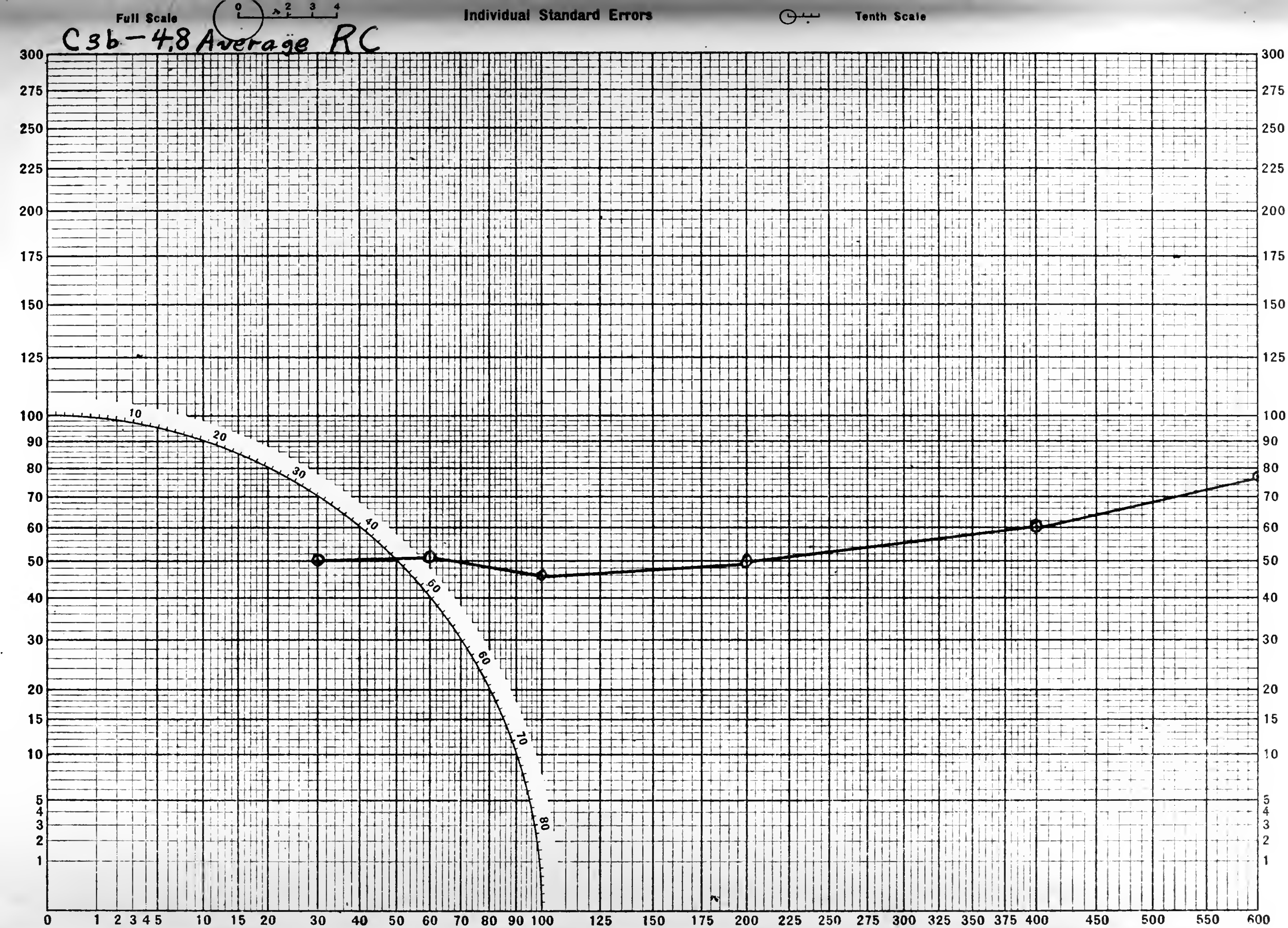
Cad-5.8 Average RC

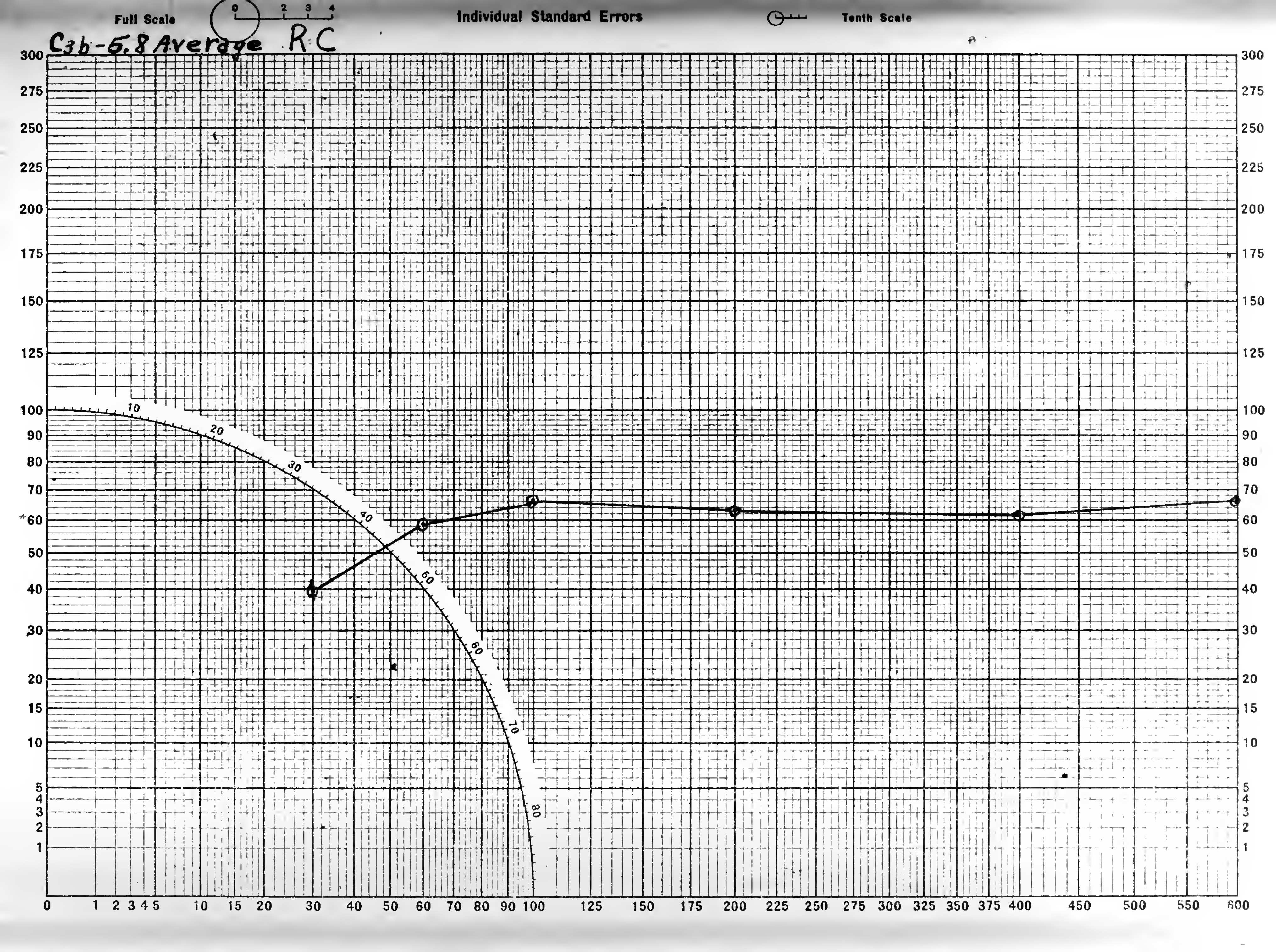



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
C3a-4.8 Average RC
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80


Full Scale
Individual Standard Errors
Tenth Scale
C3a-5.8 Average
RC

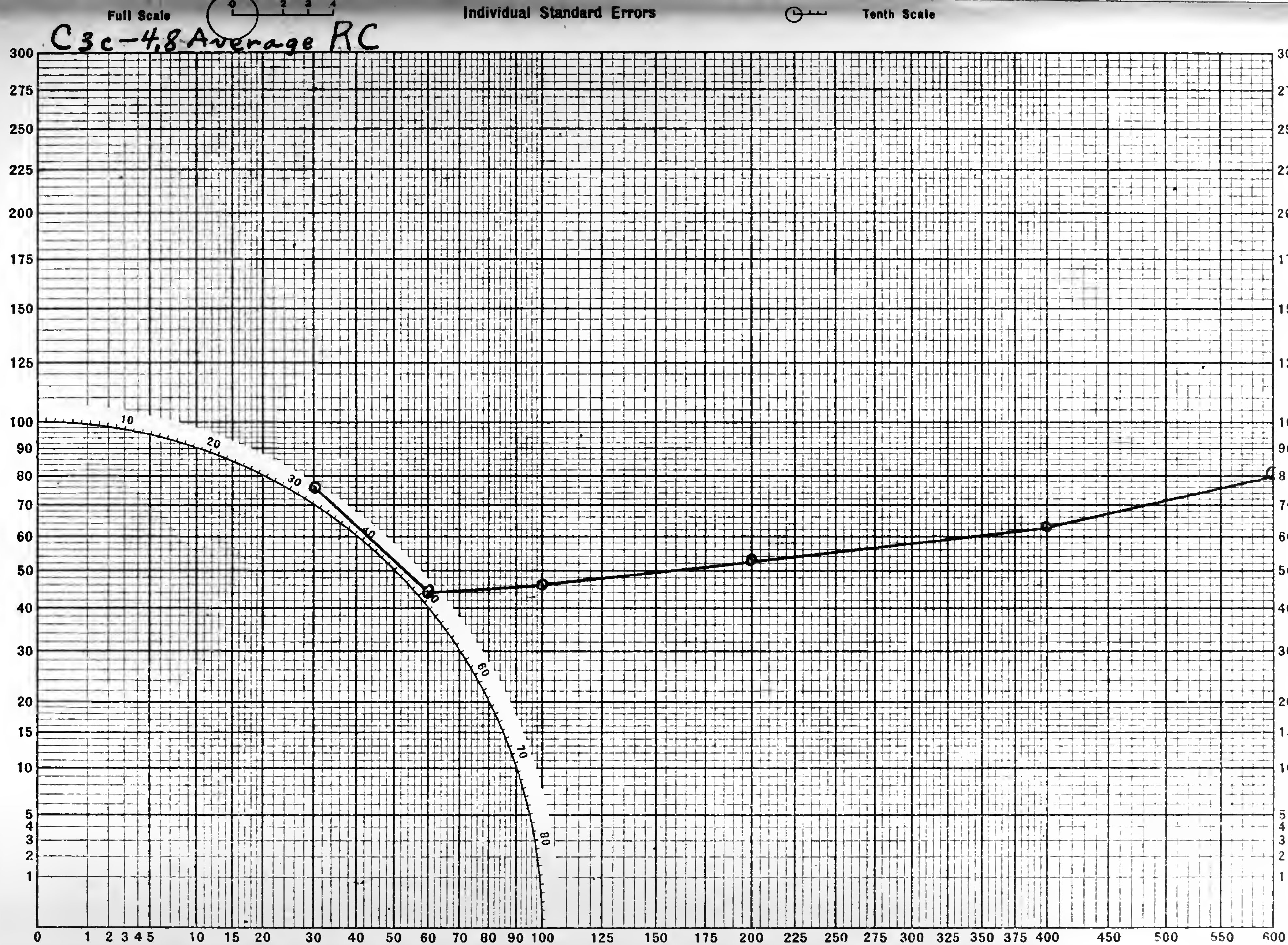
C3b-4.8 Average RC

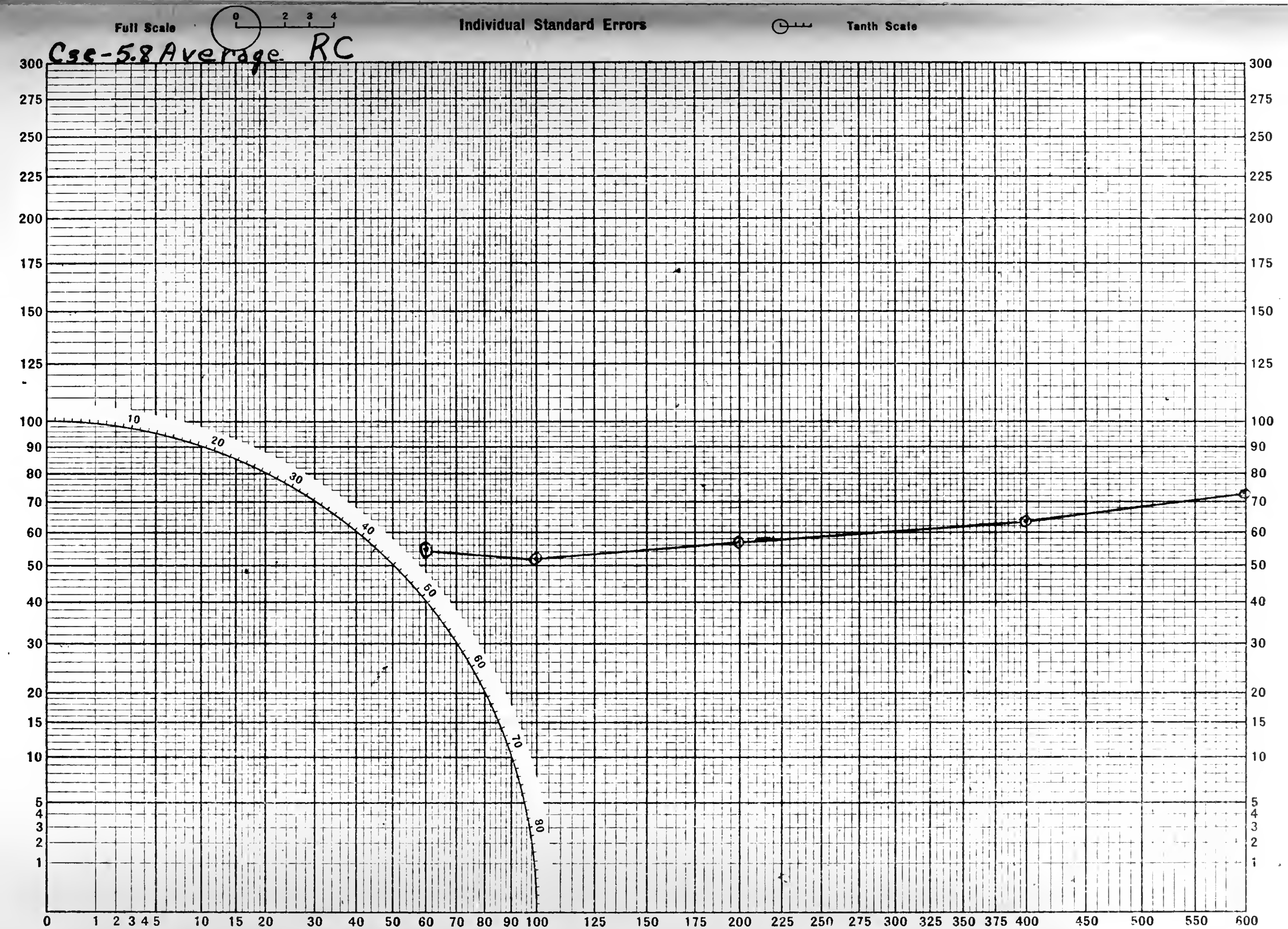


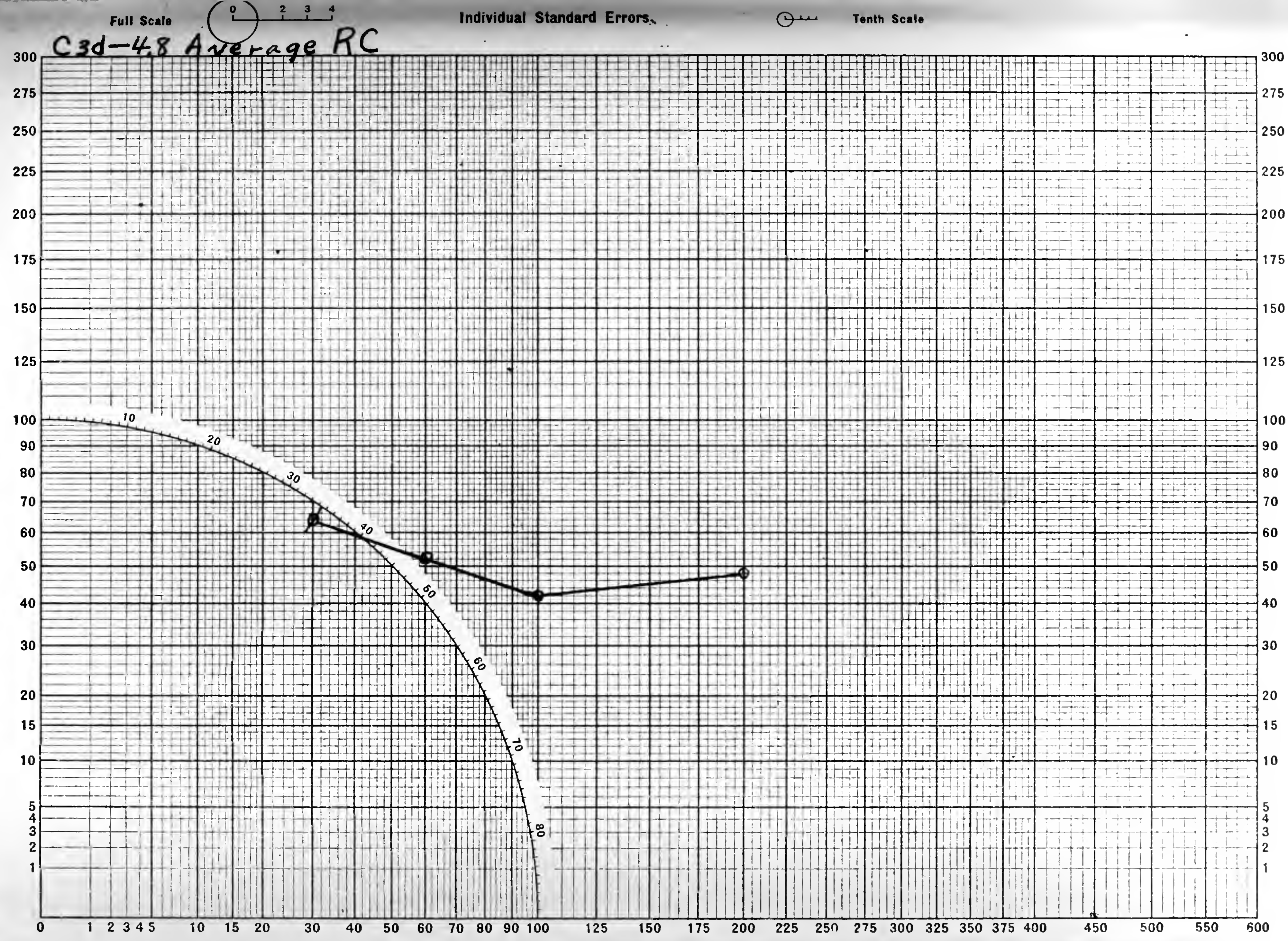

Full Scale
Individual Standard Errors
Tenth Scale
C3b-5.8 Average R C

Full Scale — Individual Standard Errors — Tenth Scale

C3c-4.8 Average RC




Full Scale
0 2 3 4
Individual Standard Errors
Tanth Scale
Cse-5.8 Average RC



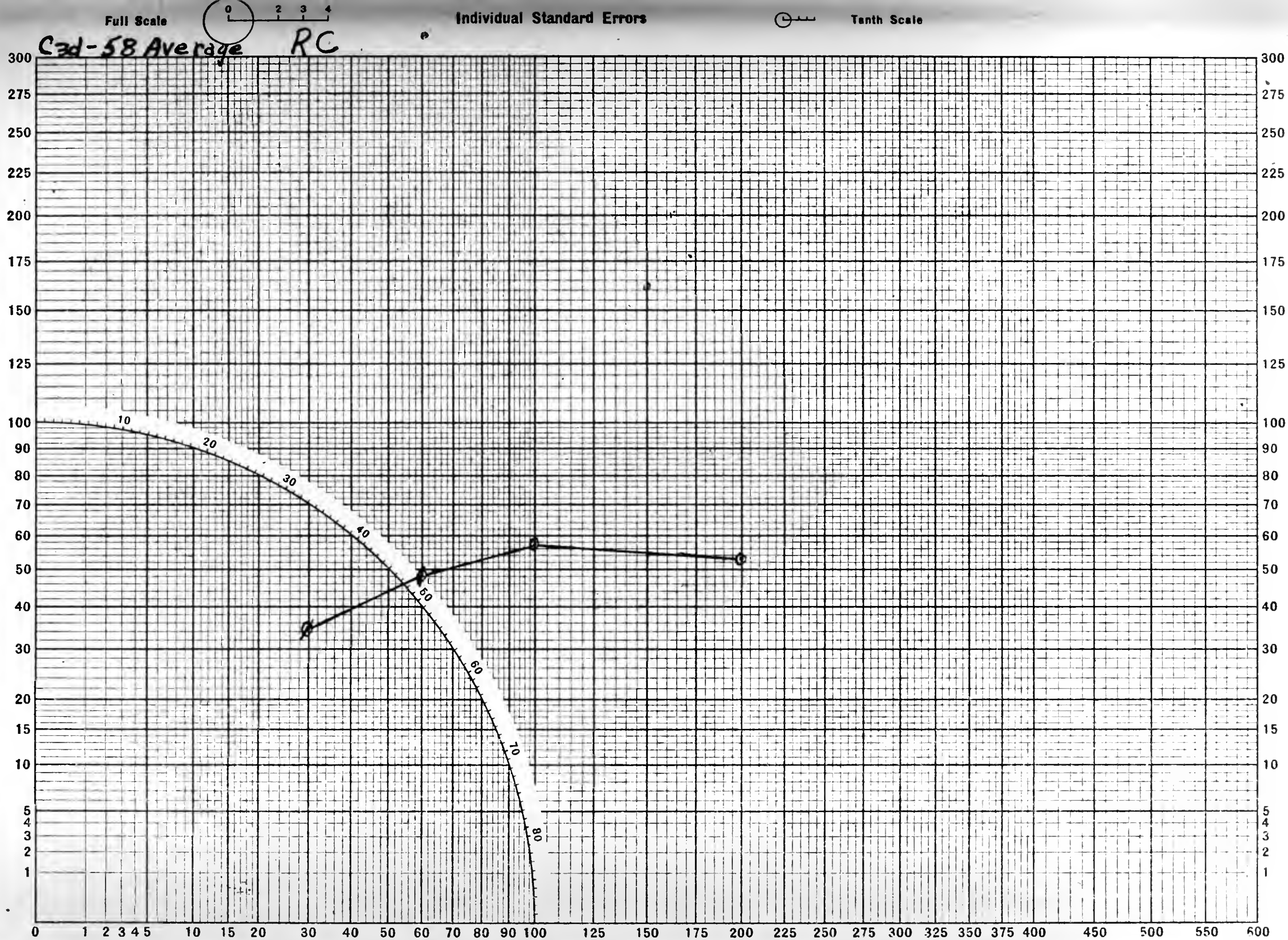
Full Scale
Individual Standard Errors
Tenth Scale
C3d-4.8 Average RC

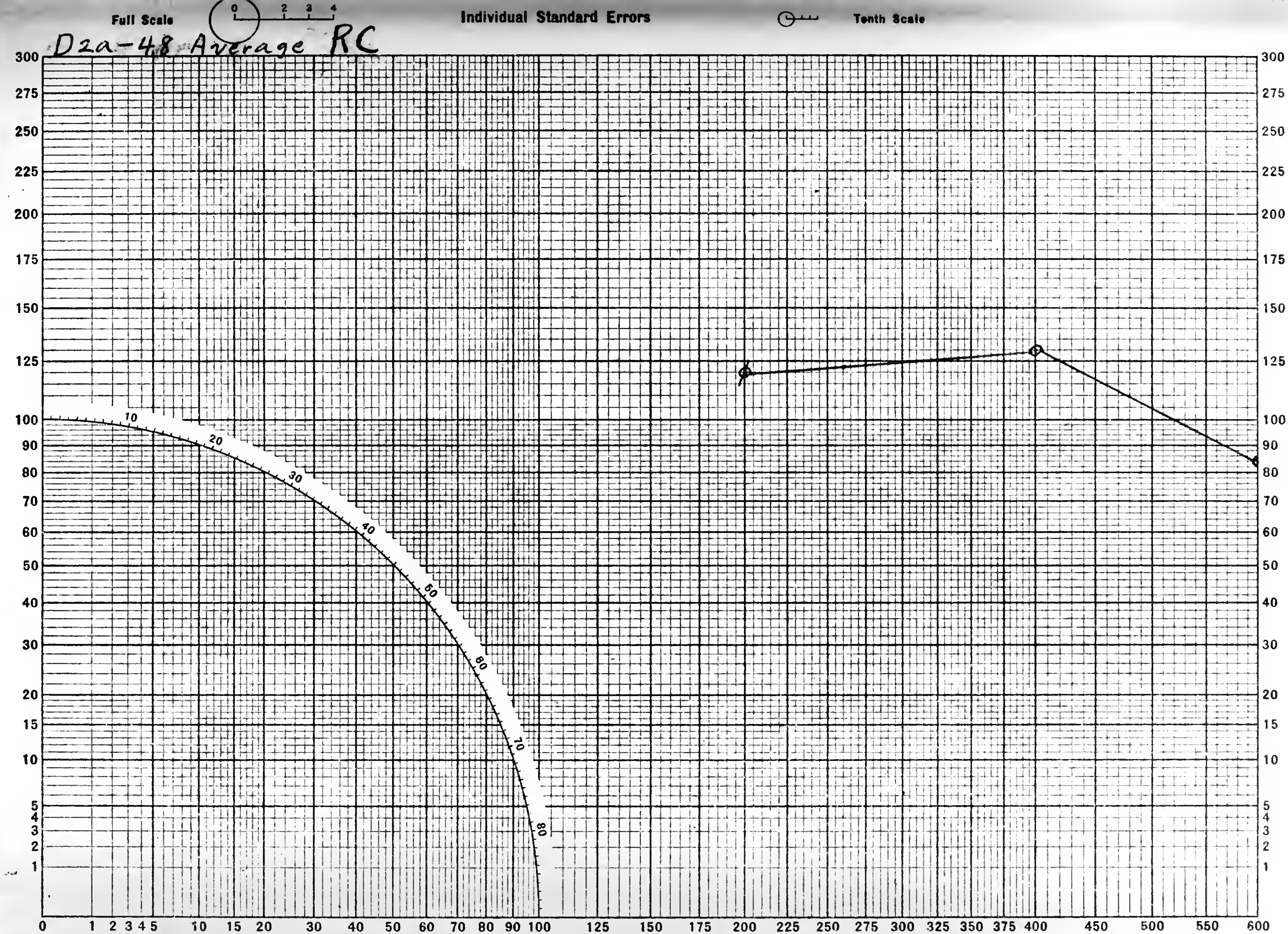
Full Scale

Individual Standard Errors

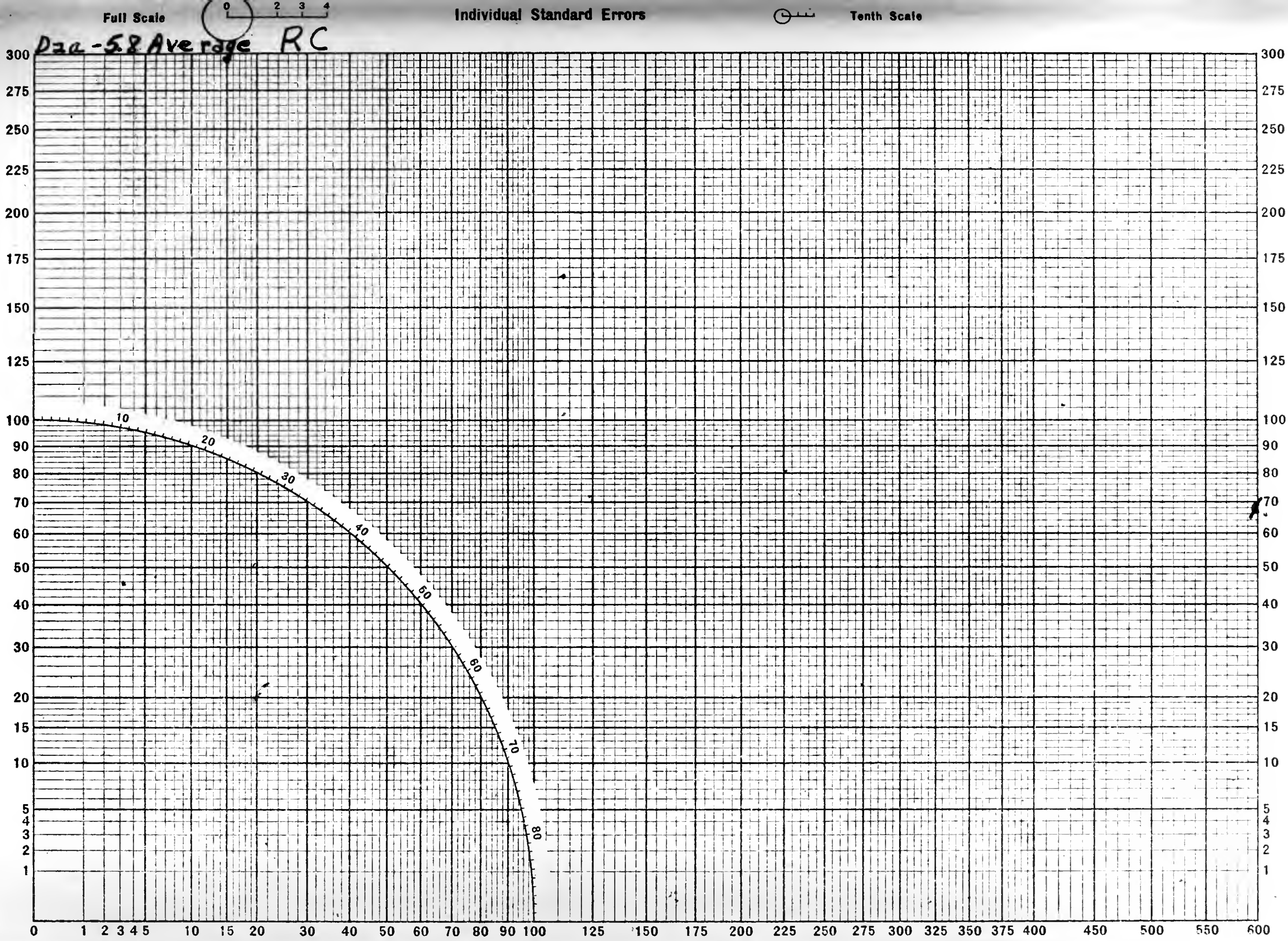
Tenth Scale

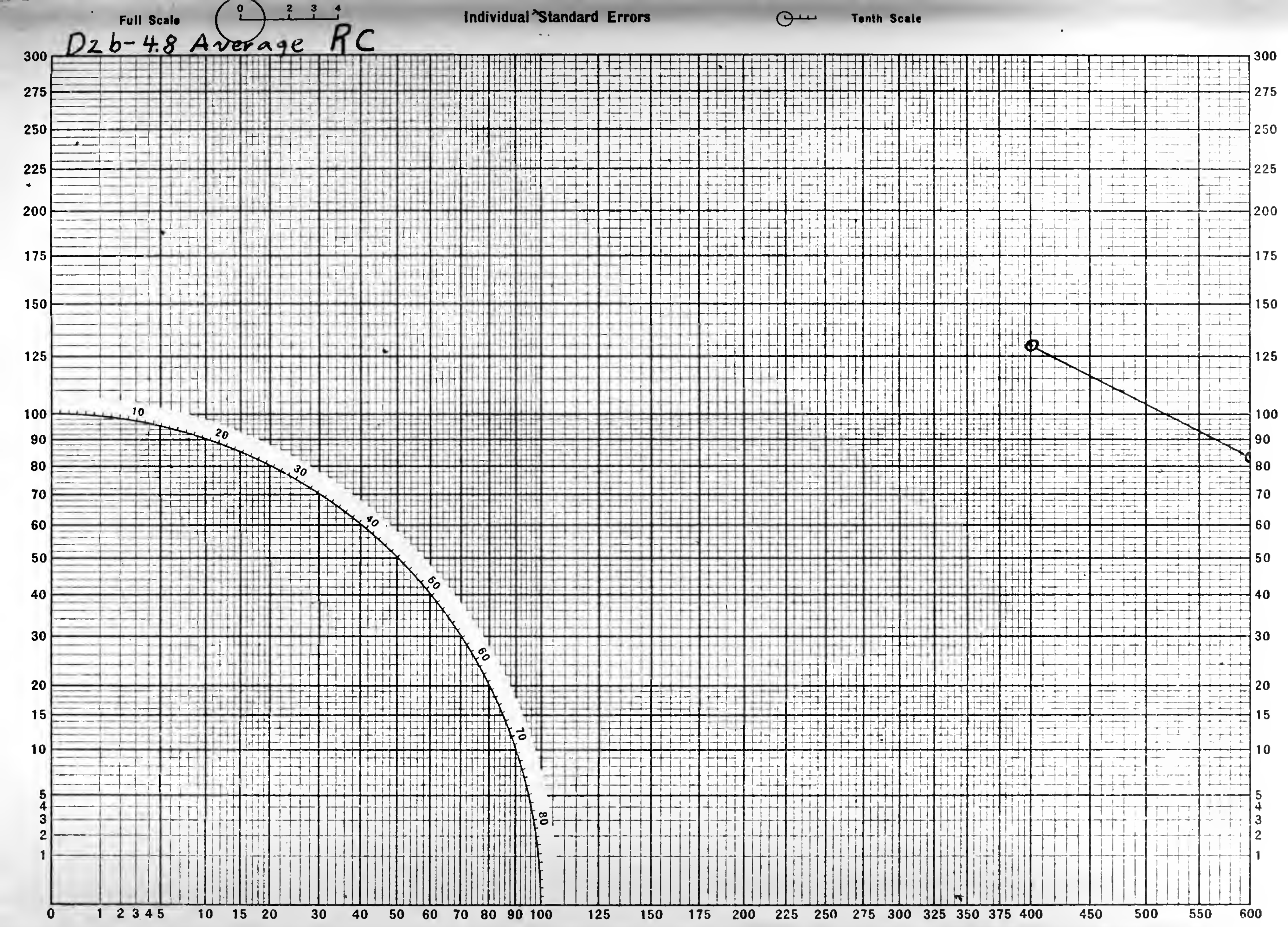
C3d-58 Average RC

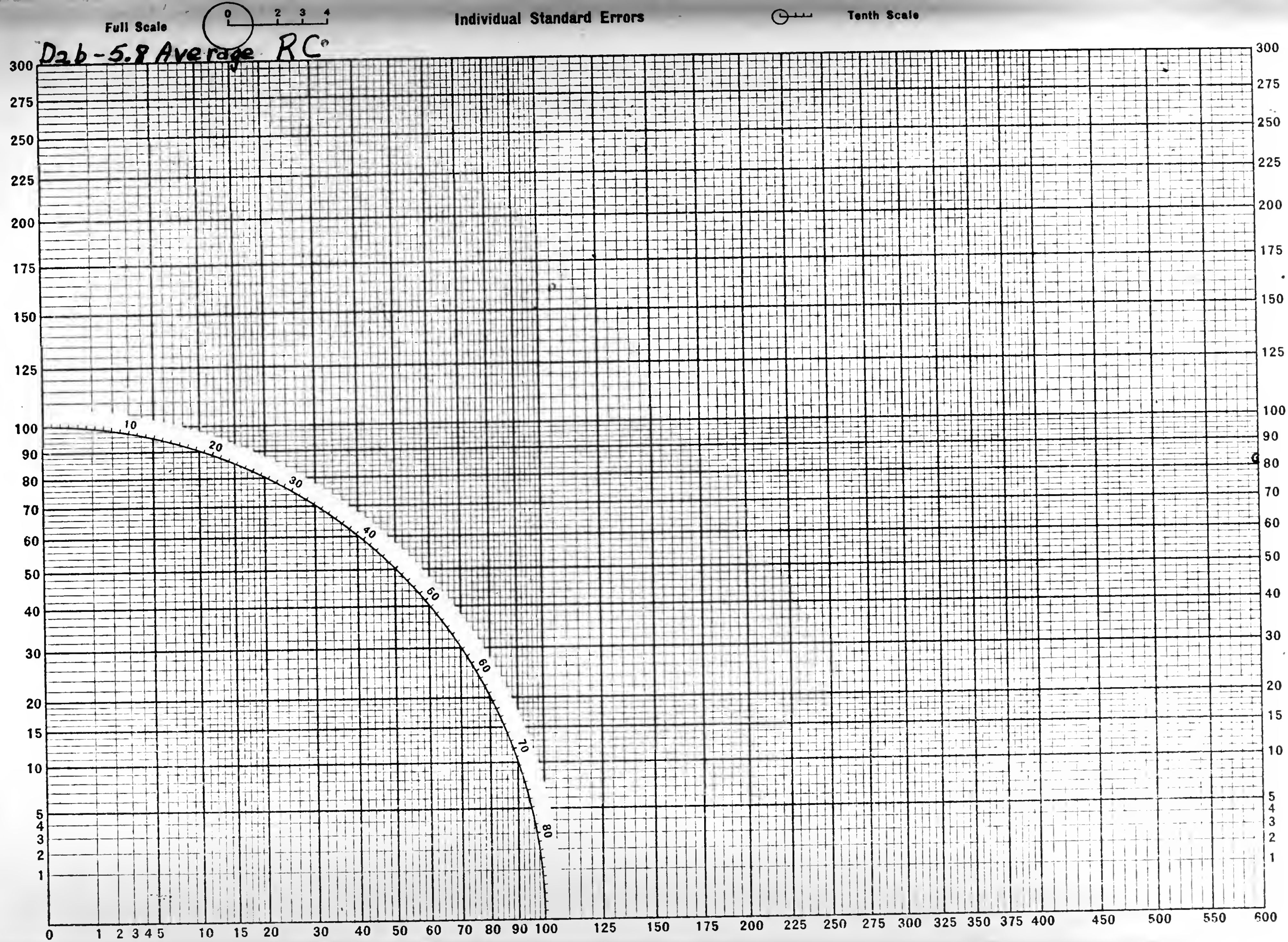




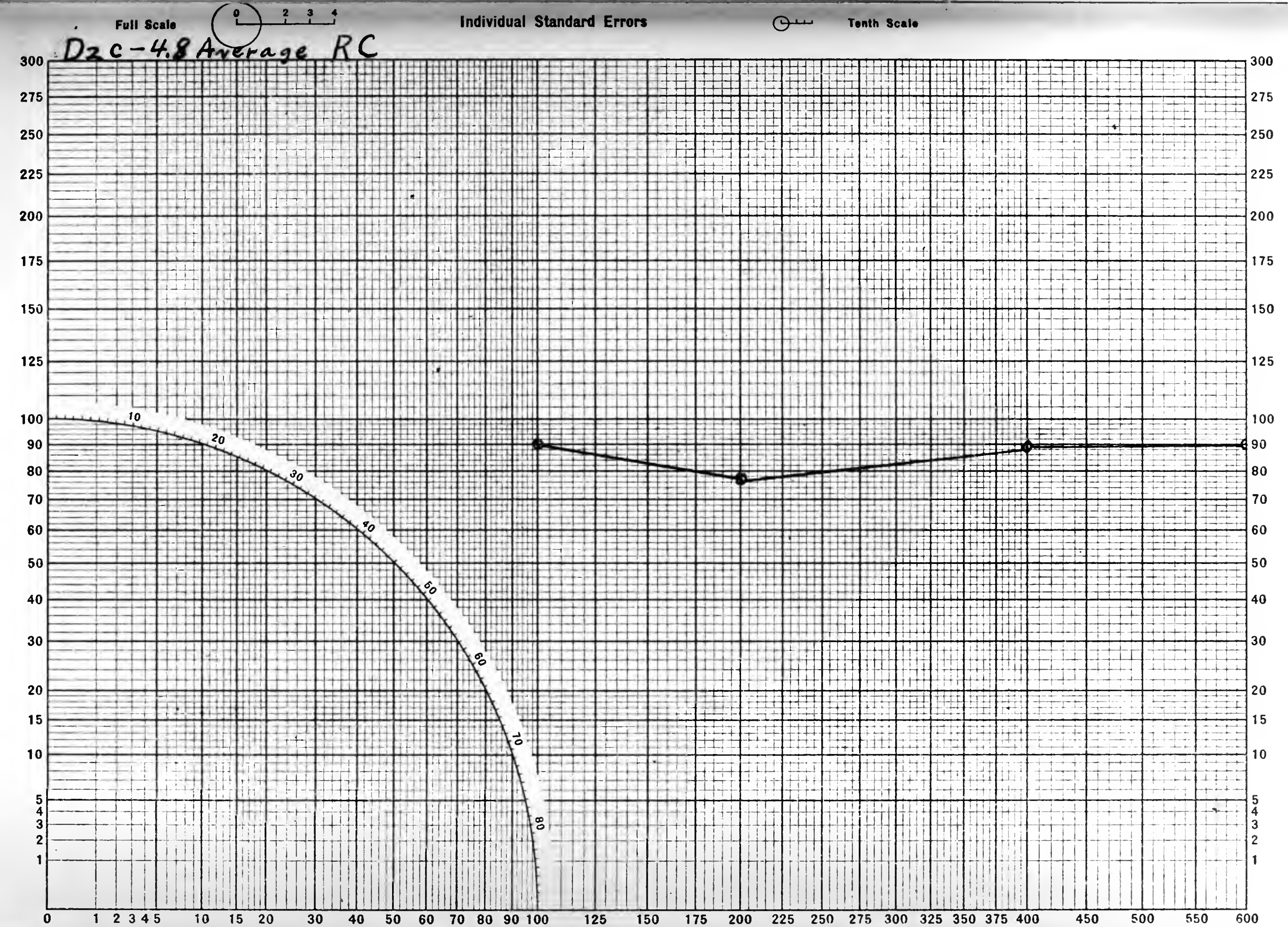
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2a-48 Average RC


Full Scale
Individual Standard Errors
Tenth Scale
Dza-58 Average
RC


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2b-4.8 Average RC

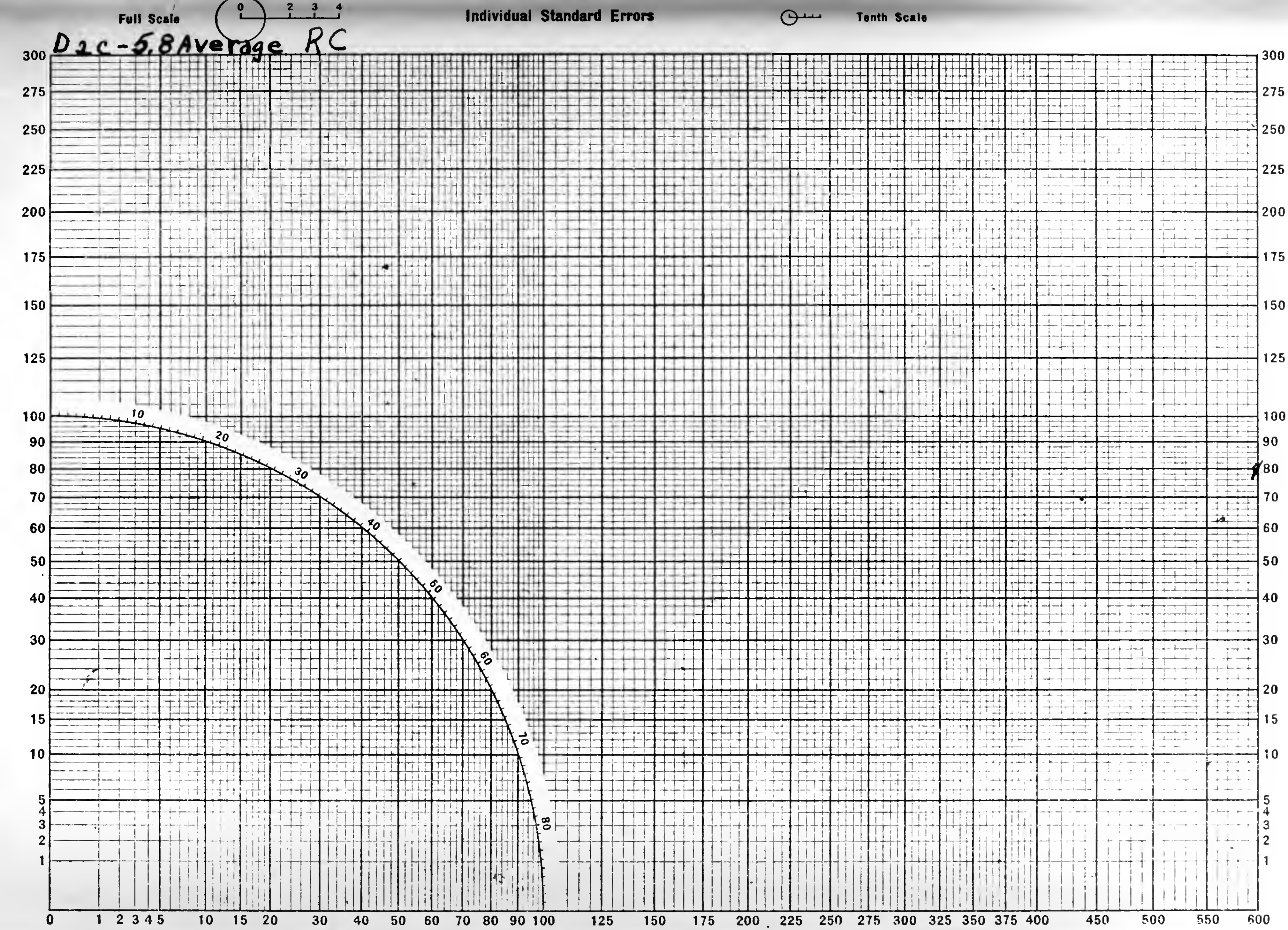


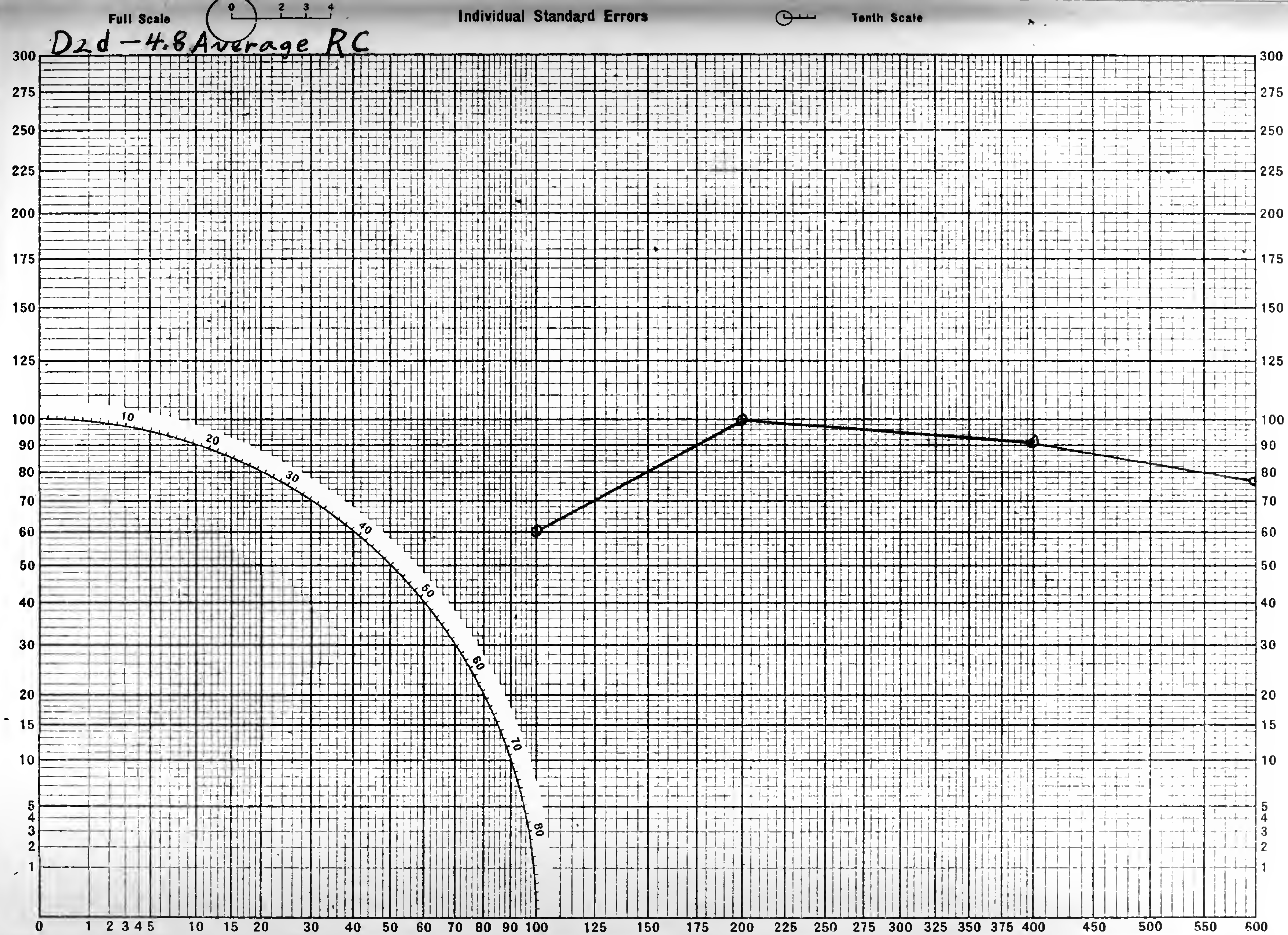
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
Dab-5.8 Average RC


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2 c-4.8 Average RC
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80

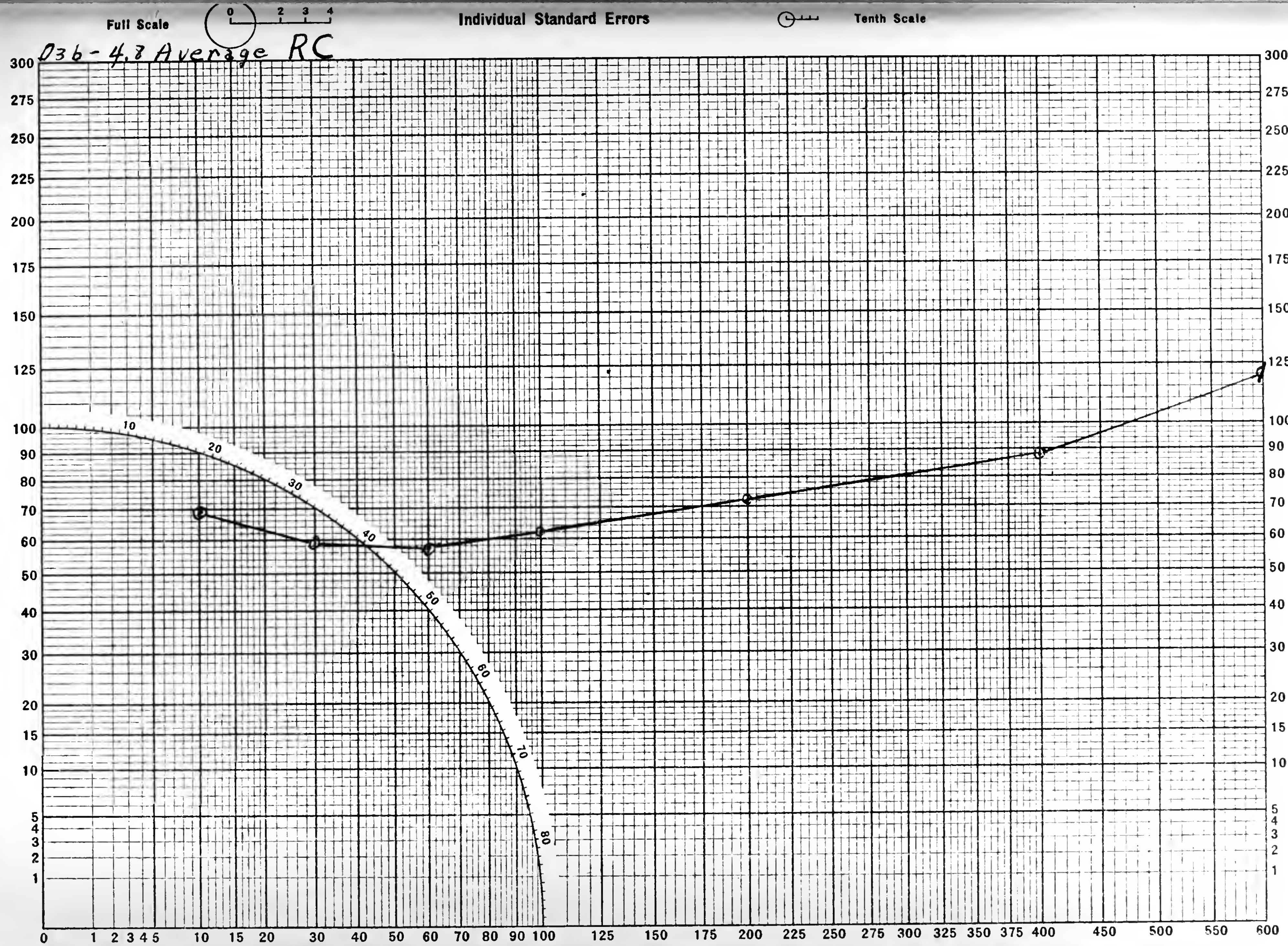
Individual Standard Errors

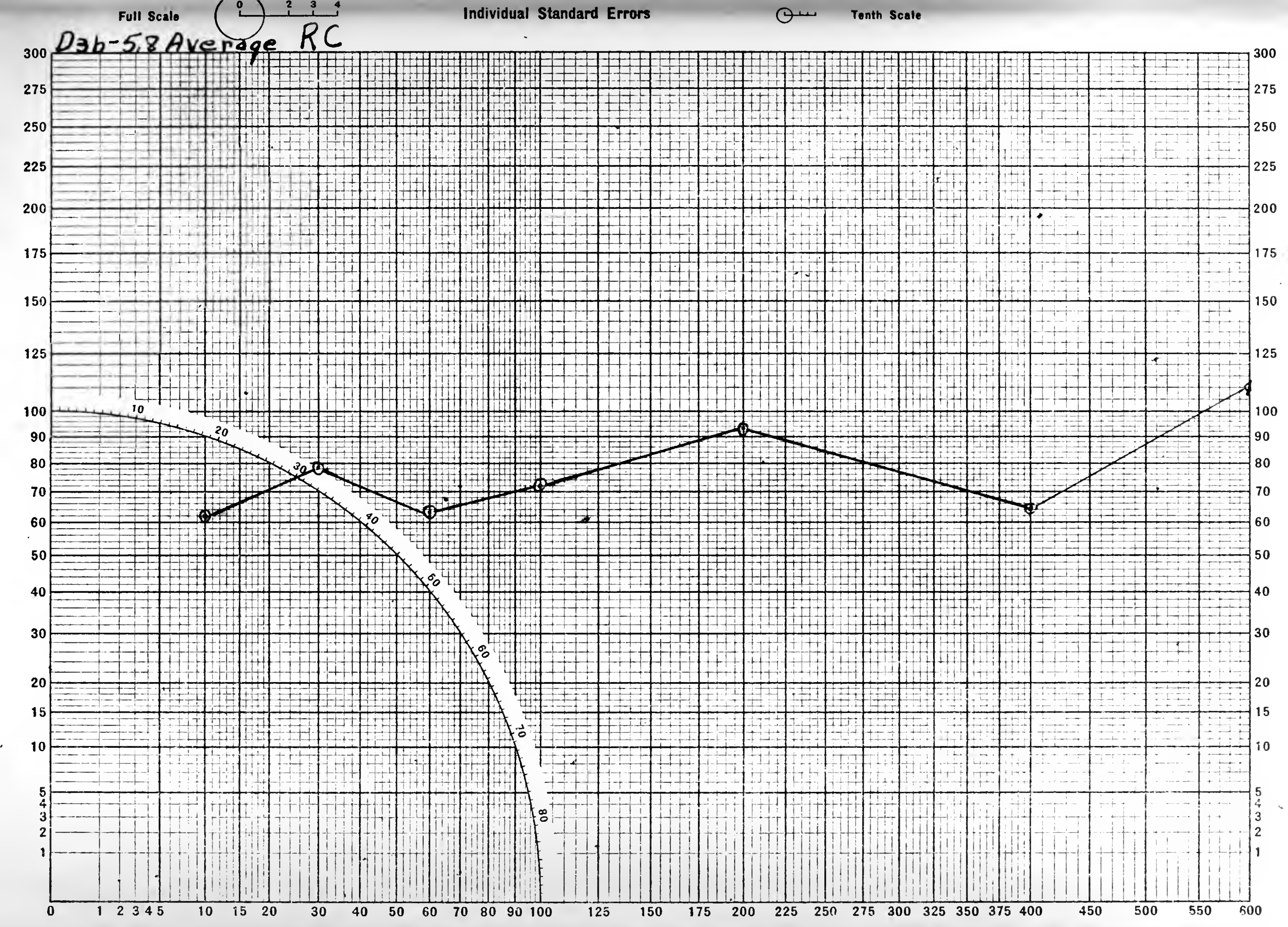
D2c-5.8 Average RC



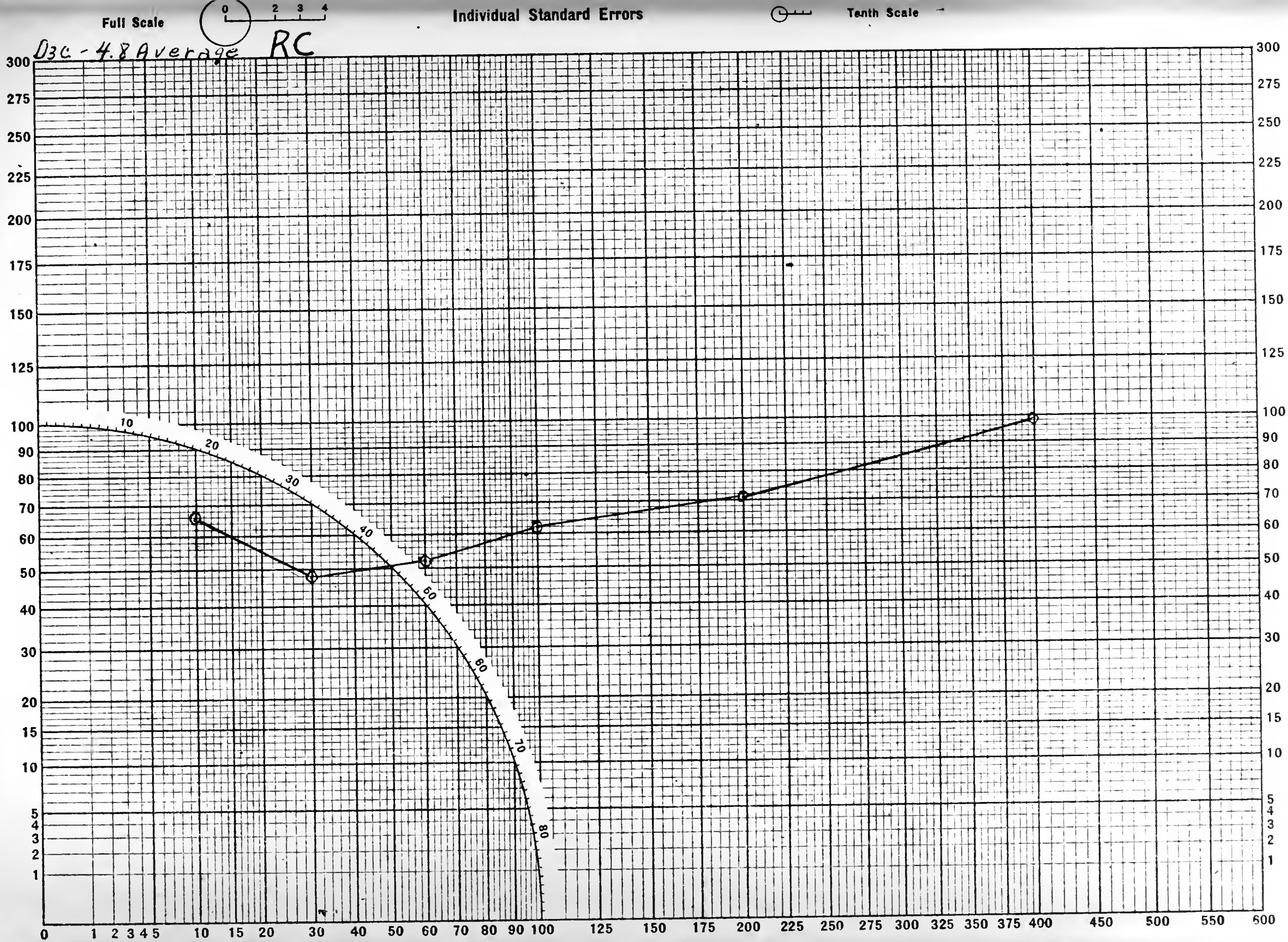

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2d -4.8 Average RC
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10
20
30
40
50
60
70
80

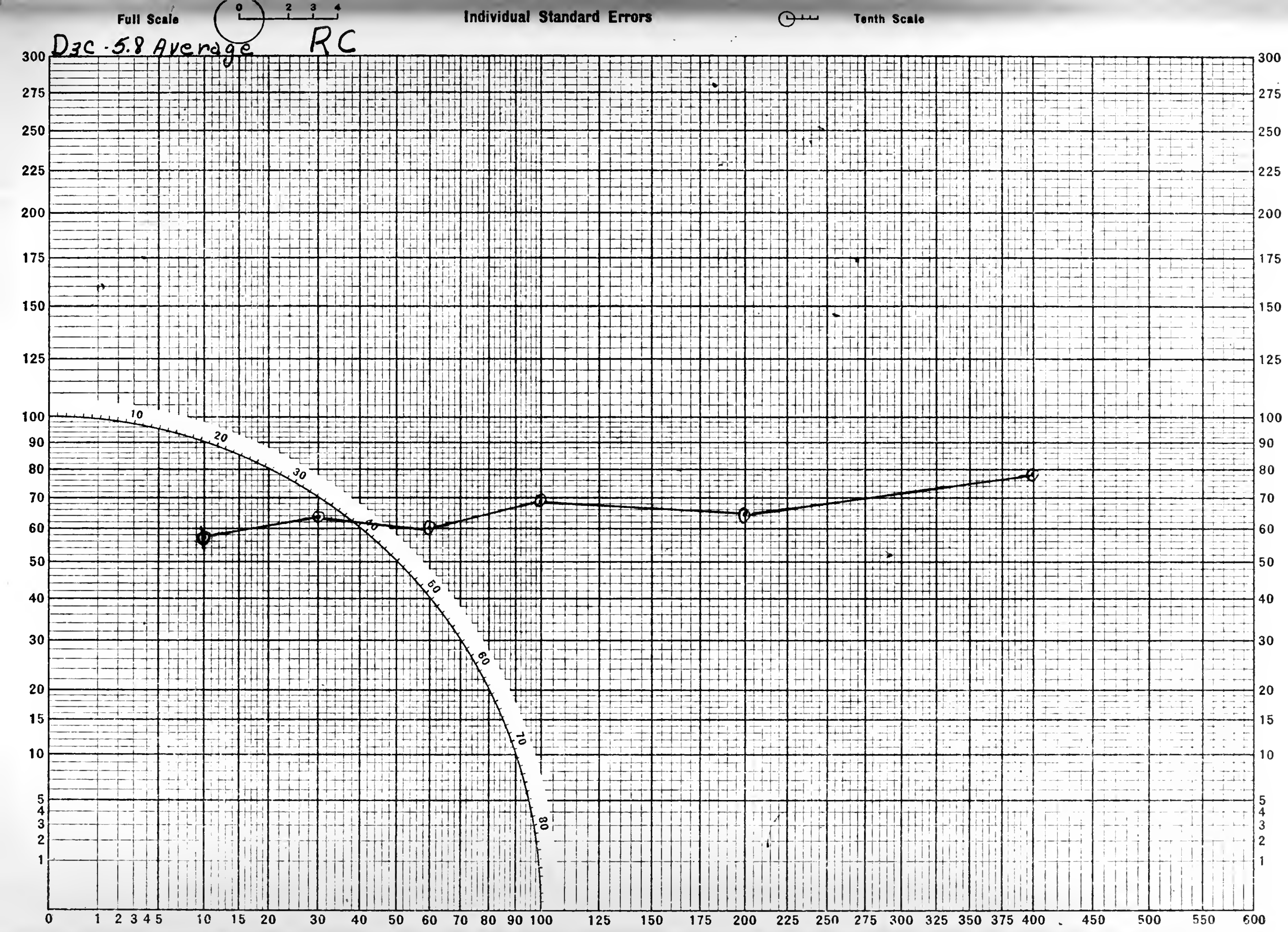

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2d-5.8 Average RC


Full Scale
Individual Standard Errors
Tenth Scale
036-4.8 Average RC



Full Scale
Individual Standard Errors
Tenth Scale
D3b-5.8 Average RC

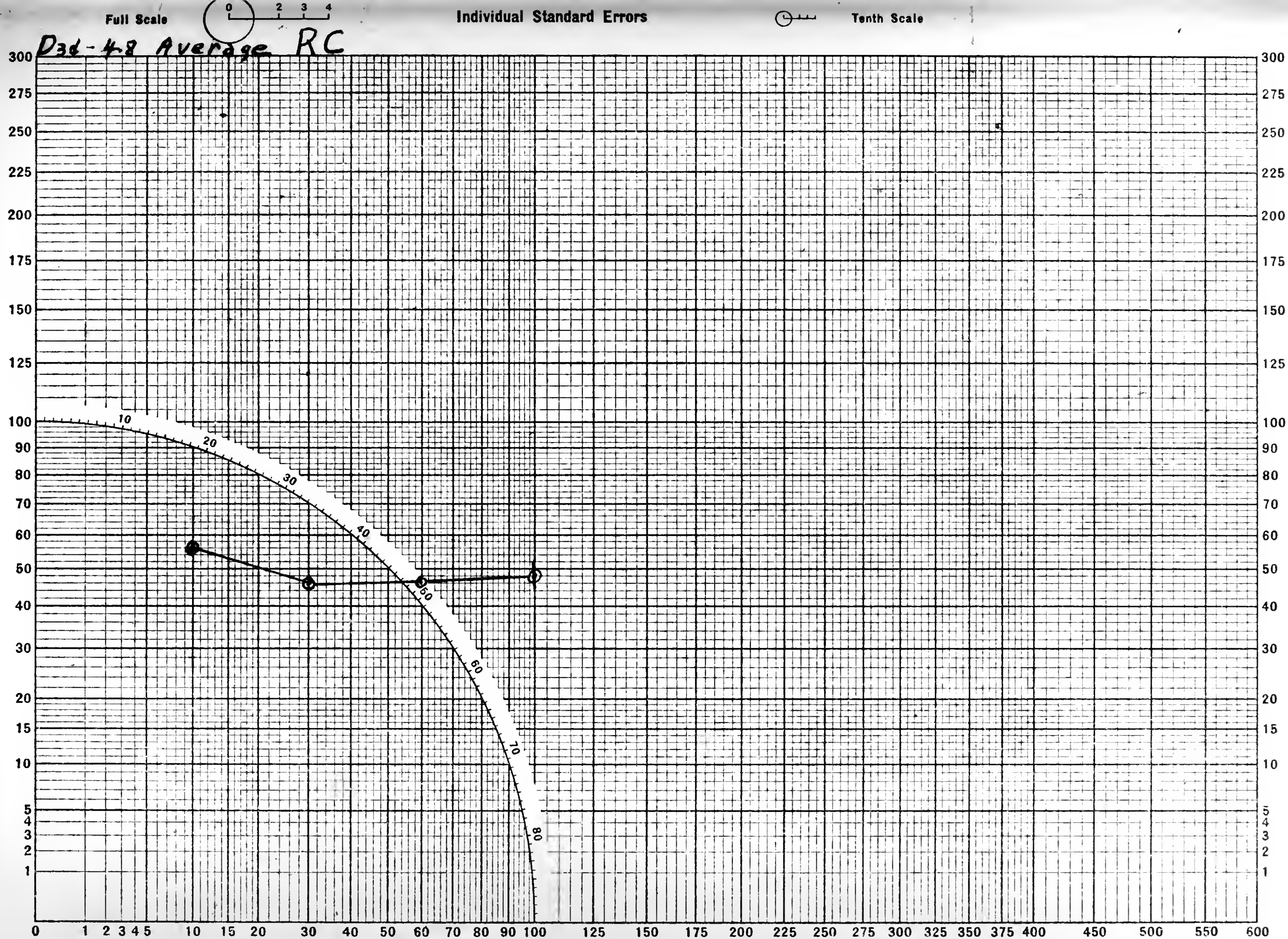

Full Scale
Individual Standard Errors
Tenth Scale
D3C - 4.8 Average
RC



Full Scale
Individual Standard Errors
Tenth Scale
D3C ·5.8 Average
RC

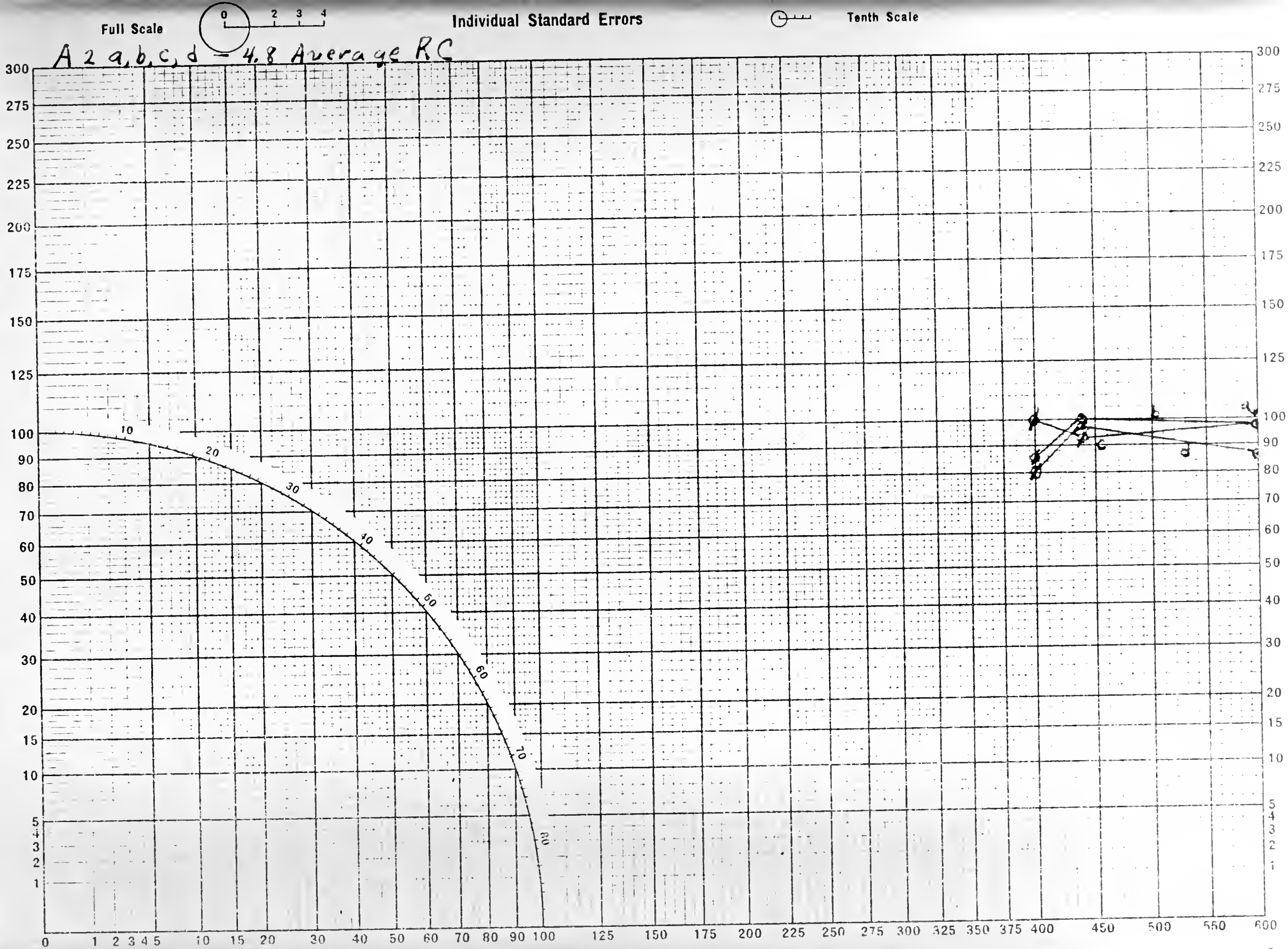
Full Scale Individual Standard Errors Tenth Scale

D3d-4-8 Average RC




Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
Dad 5.8 Average RC

AVERAGE TIME CONSTANT, COMPARING
FIELD INTENSITY AND OPERATING
CATHODE CURRENT EFFECTS



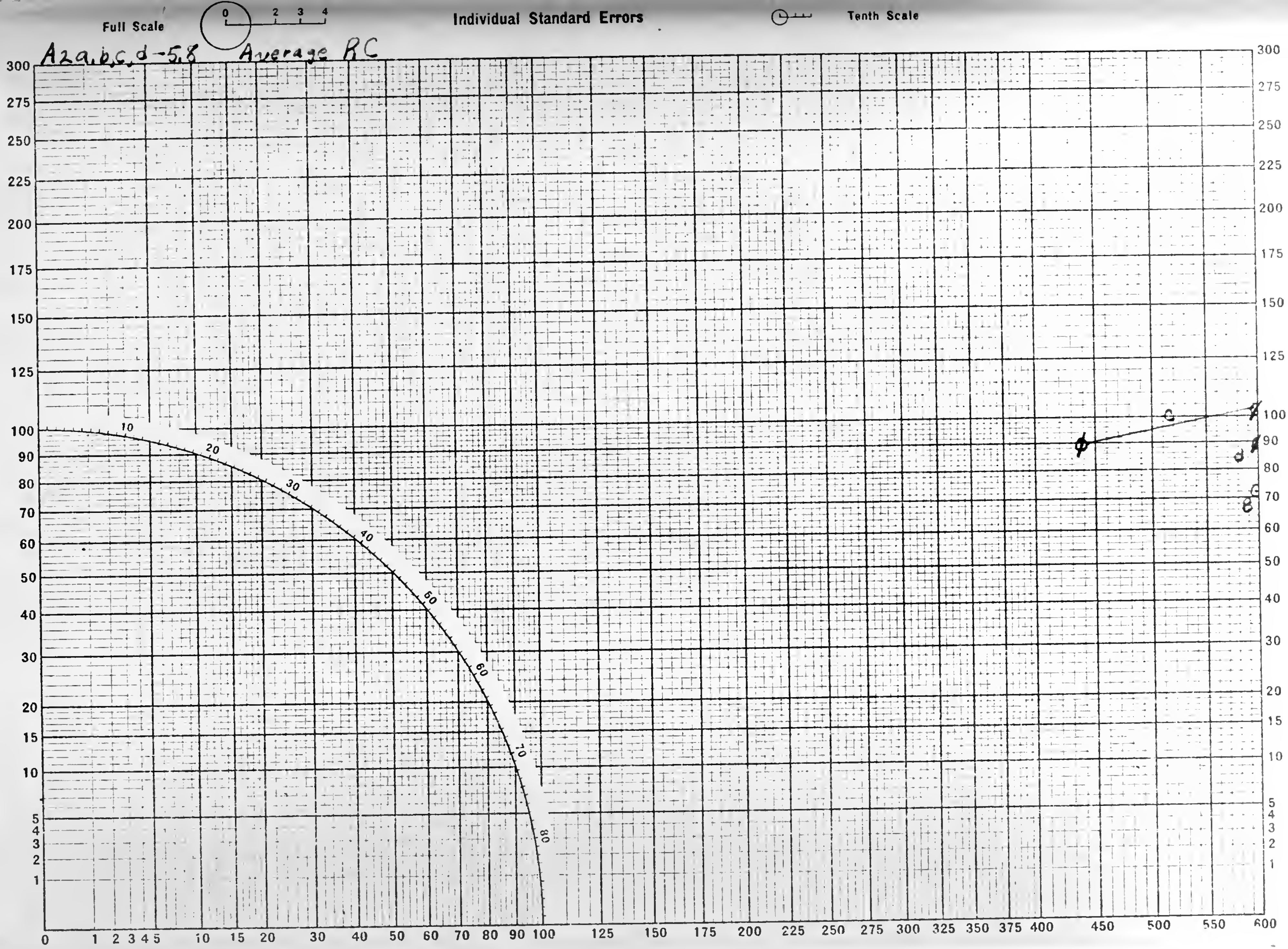
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2 a, b, c, d - 4.8 Average RC

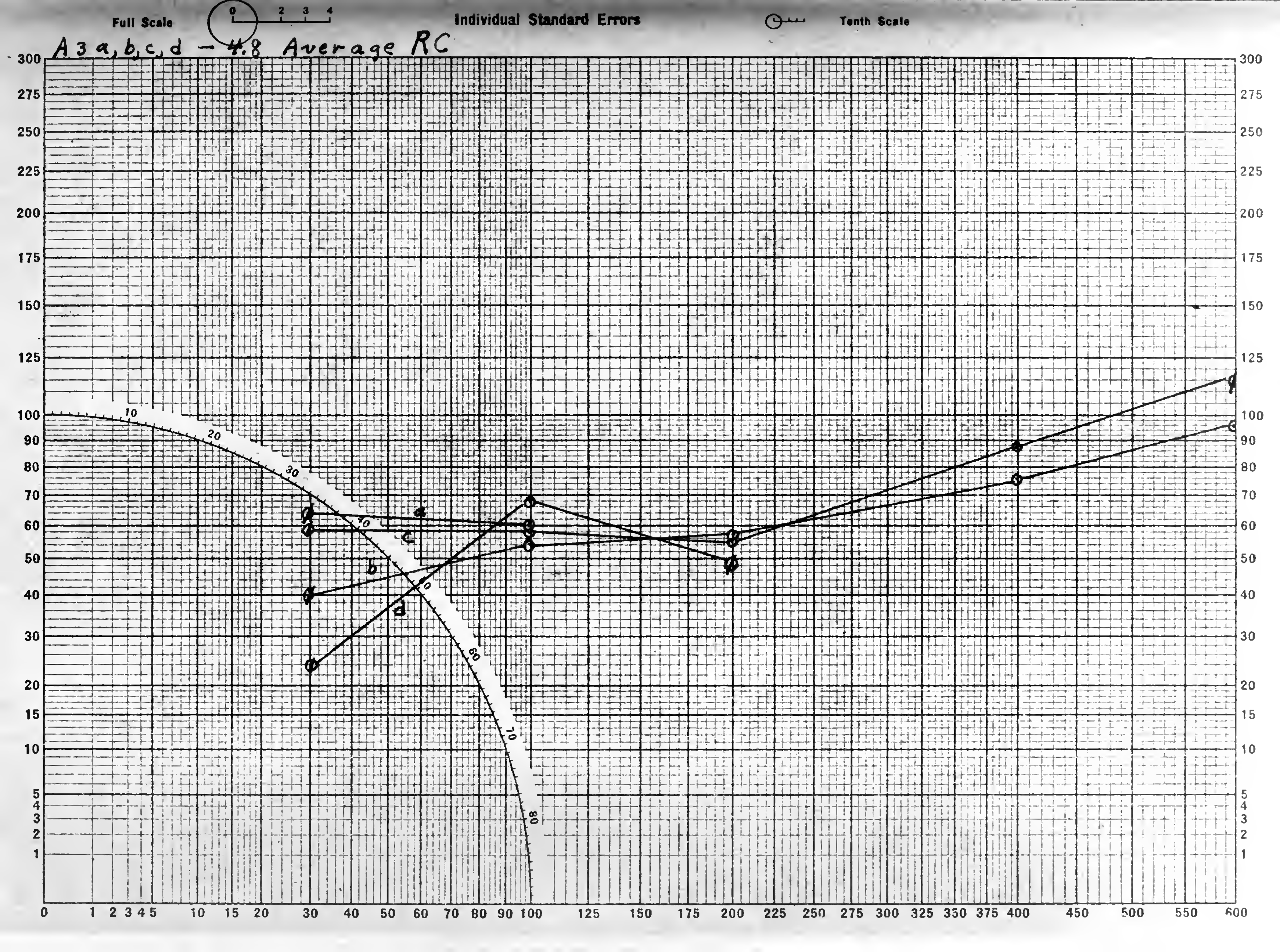
Full Scale

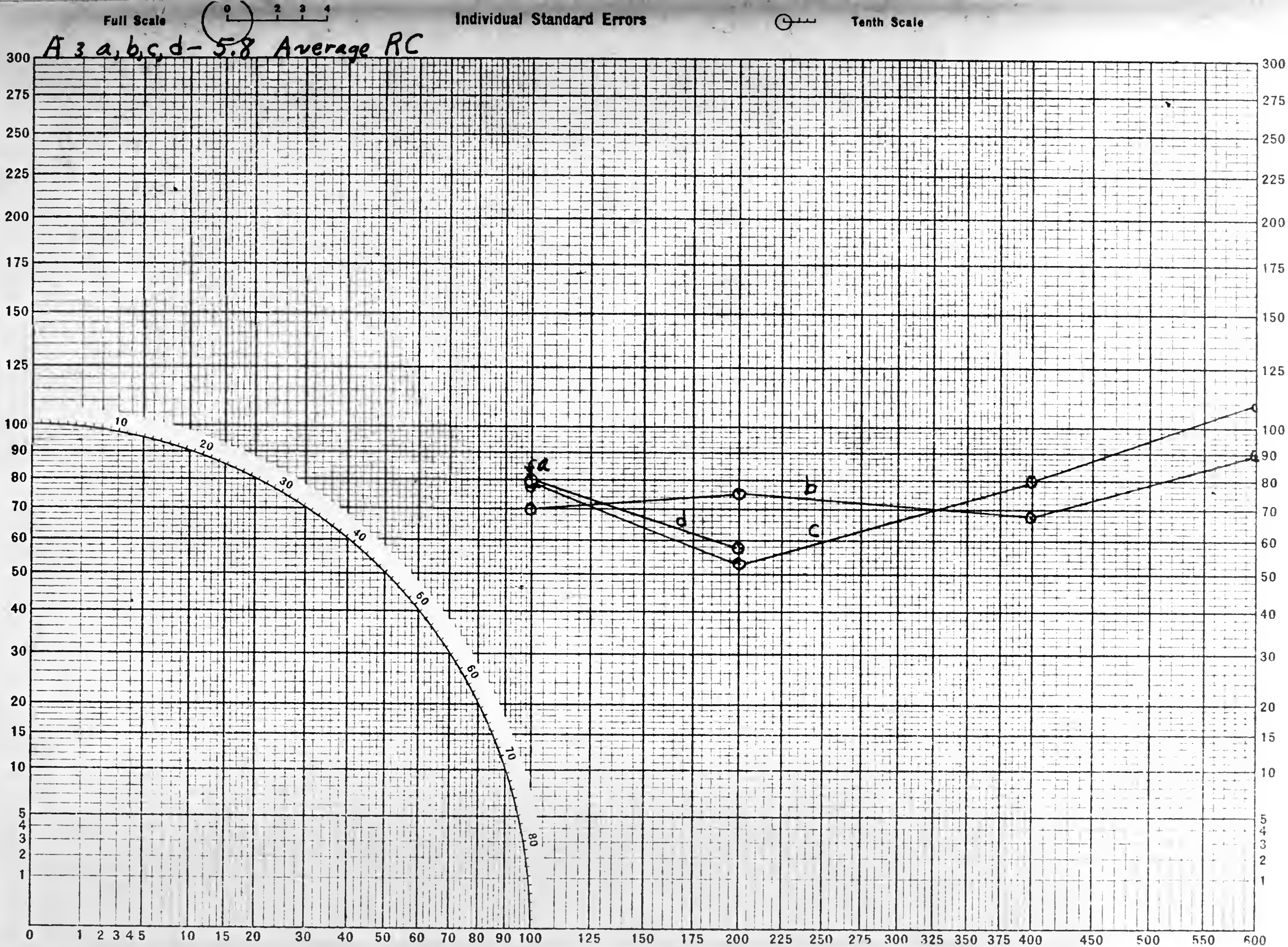
Individual Standard Errors

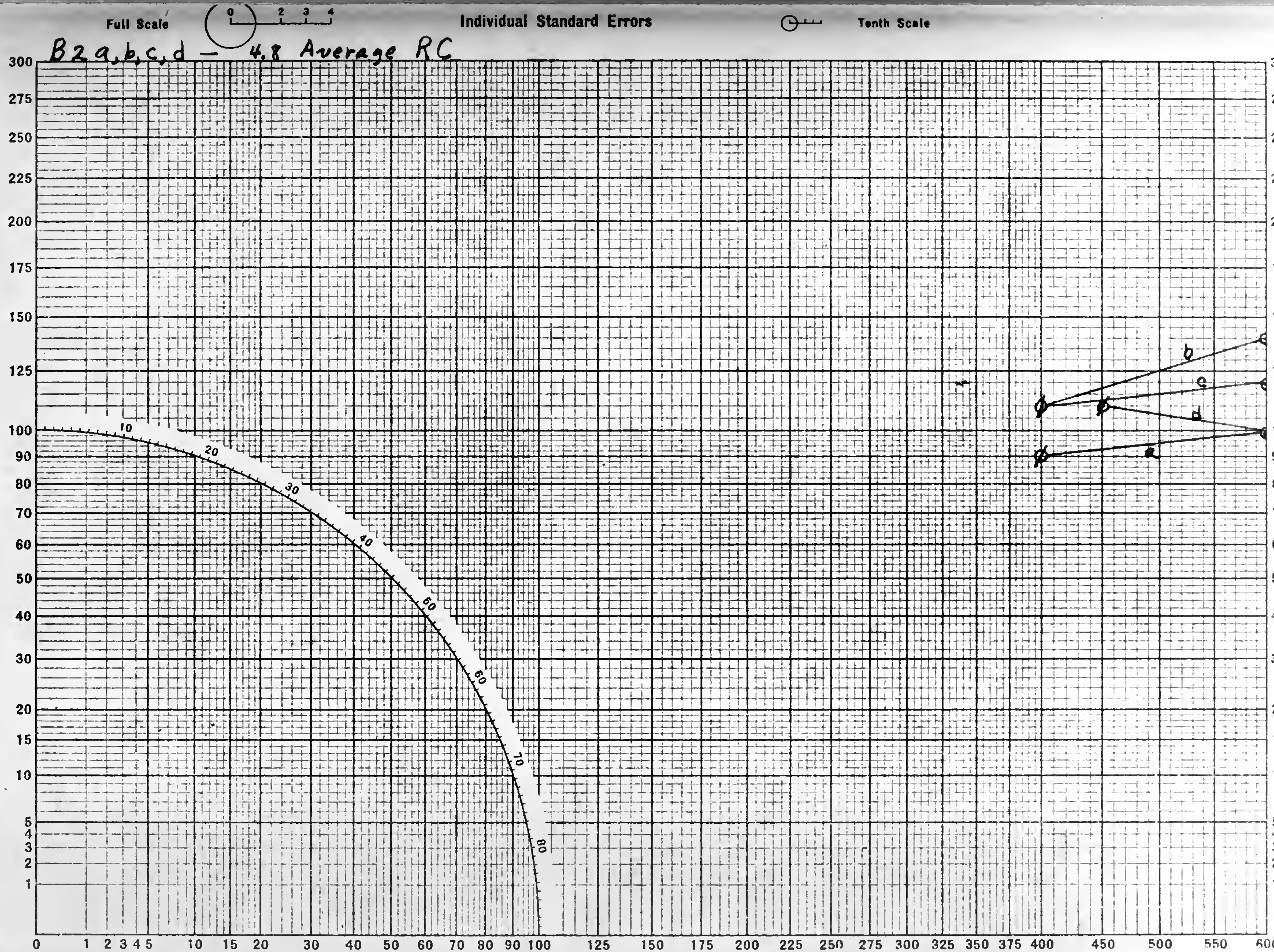
Tenth Scale

A2a,b,c,d-5.8 Average RC



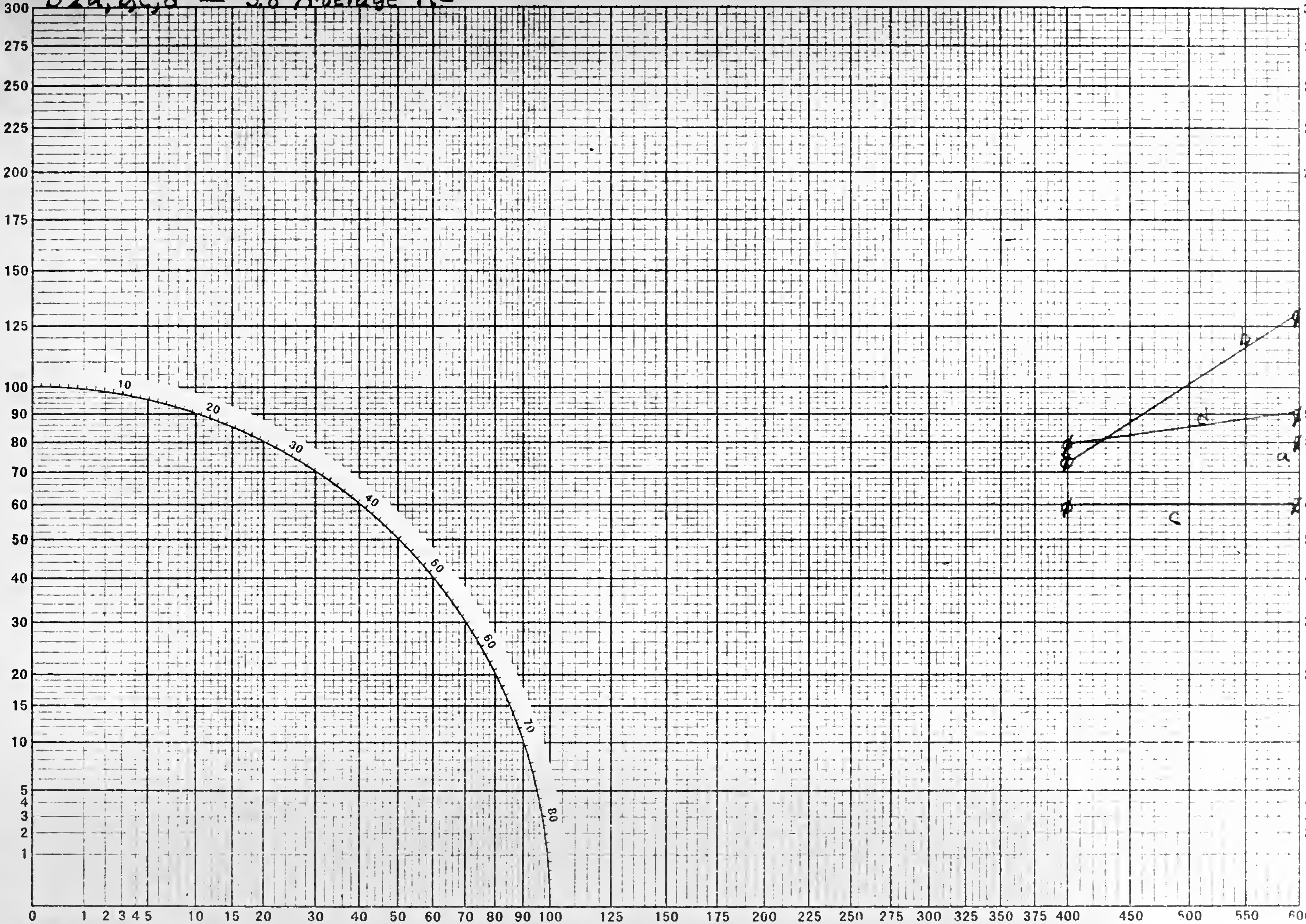

Full Scale
Individual Standard Errors
Tenth Scale
A 3 a, b, c, d — 4.8 Average RC
a
b
c
d

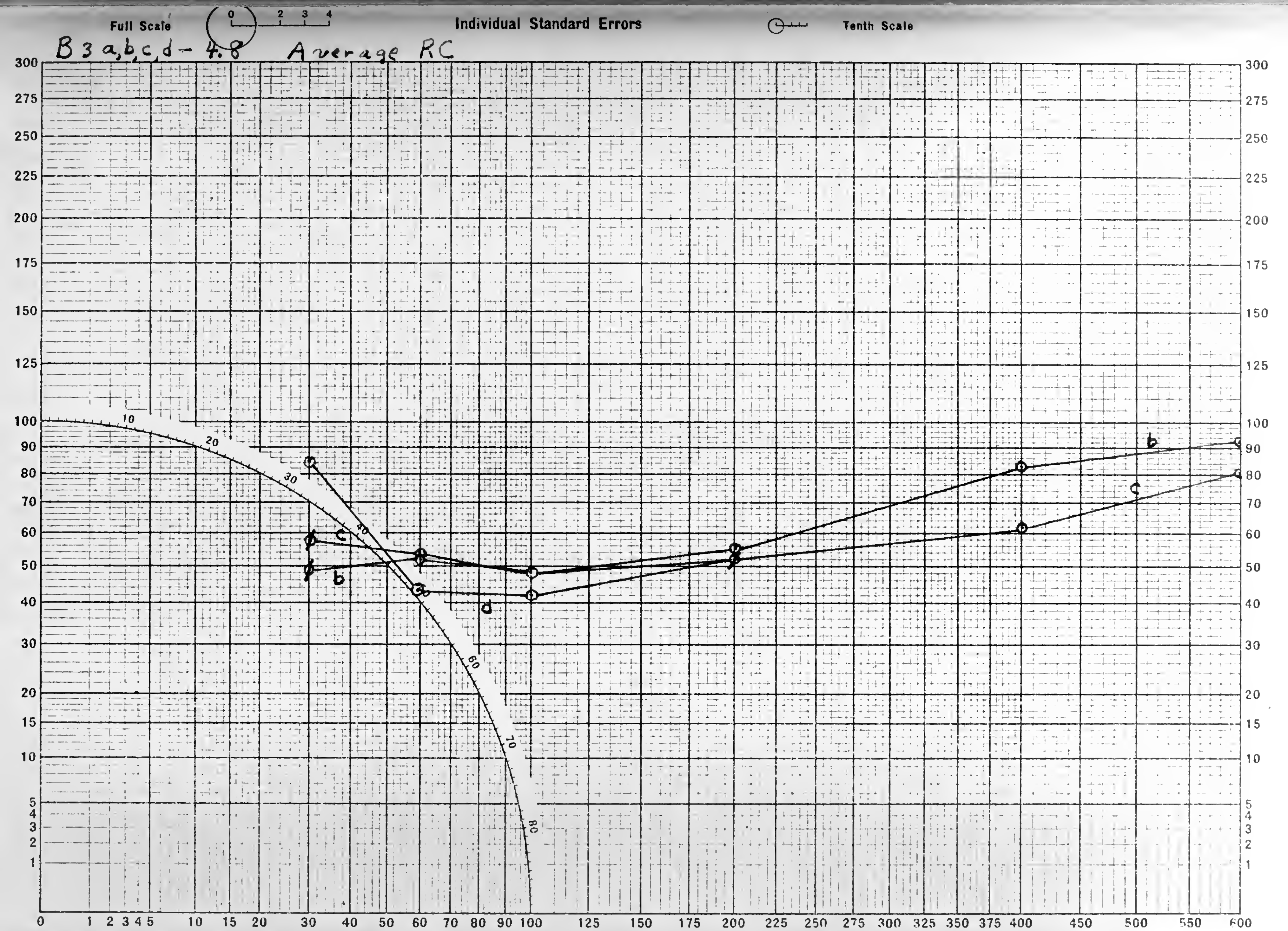

Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 3 a, b, c, d - 5.8 Average RC
a
b
c
d
300
275
250
225
200
175
150
125
100
90
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0
1 2 3 4 5
10 15 20 30 40 50 60 70 80 90 100
125 150 175 200 225 250 275 300 325 350 375 400
450 500 550 600


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B2a,b,c,d — 4.8 Average RC
a
b
c
d

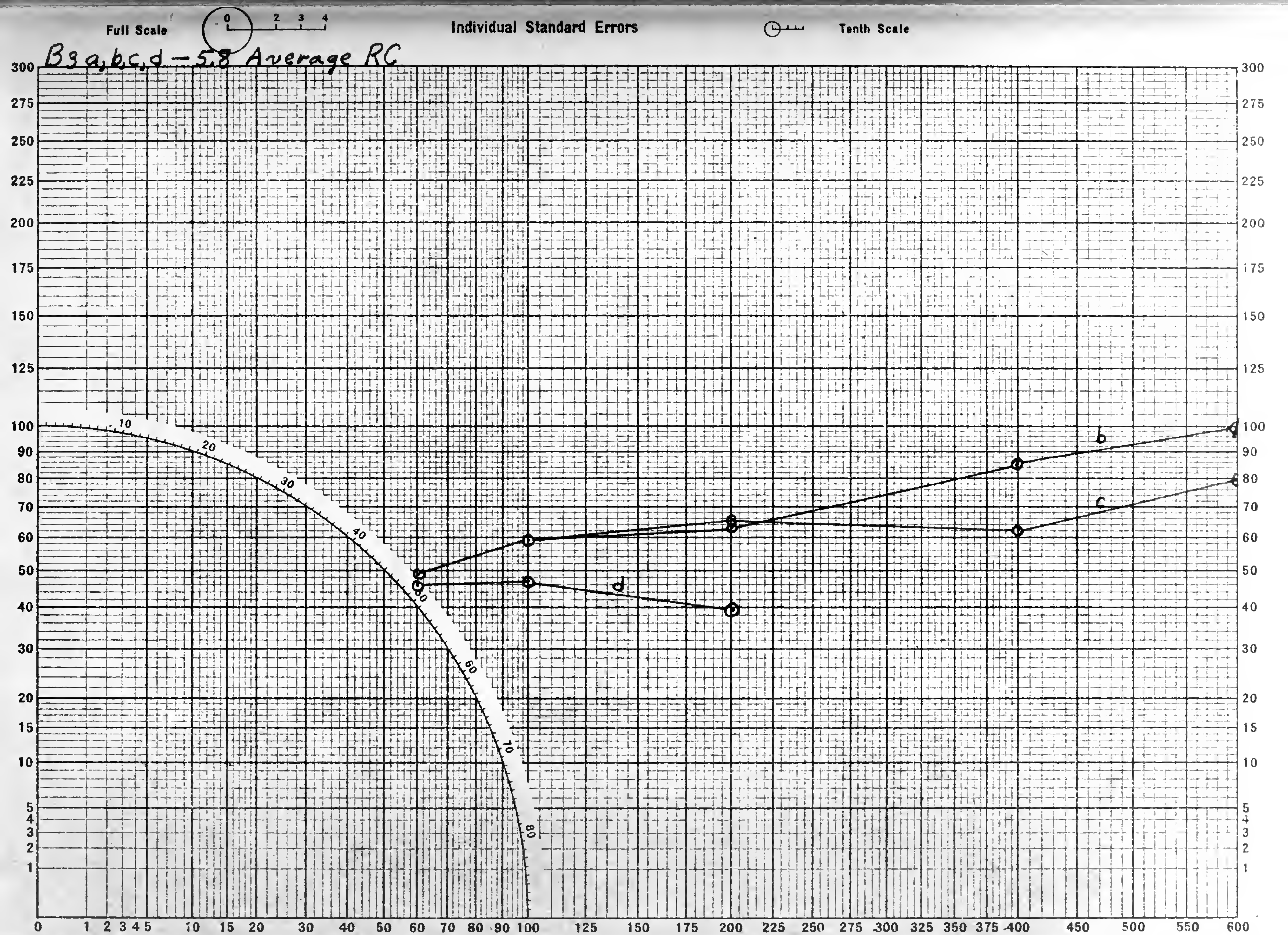
Full Scale	Individual Standard Errors	Tenth Scale

B2a,b,c,d — 5.8 Average RC -





Full Scale
Individual Standard Errors
Tenth Scale
B 3 a,b,c,d - 4.8 Average RC
b
c
d

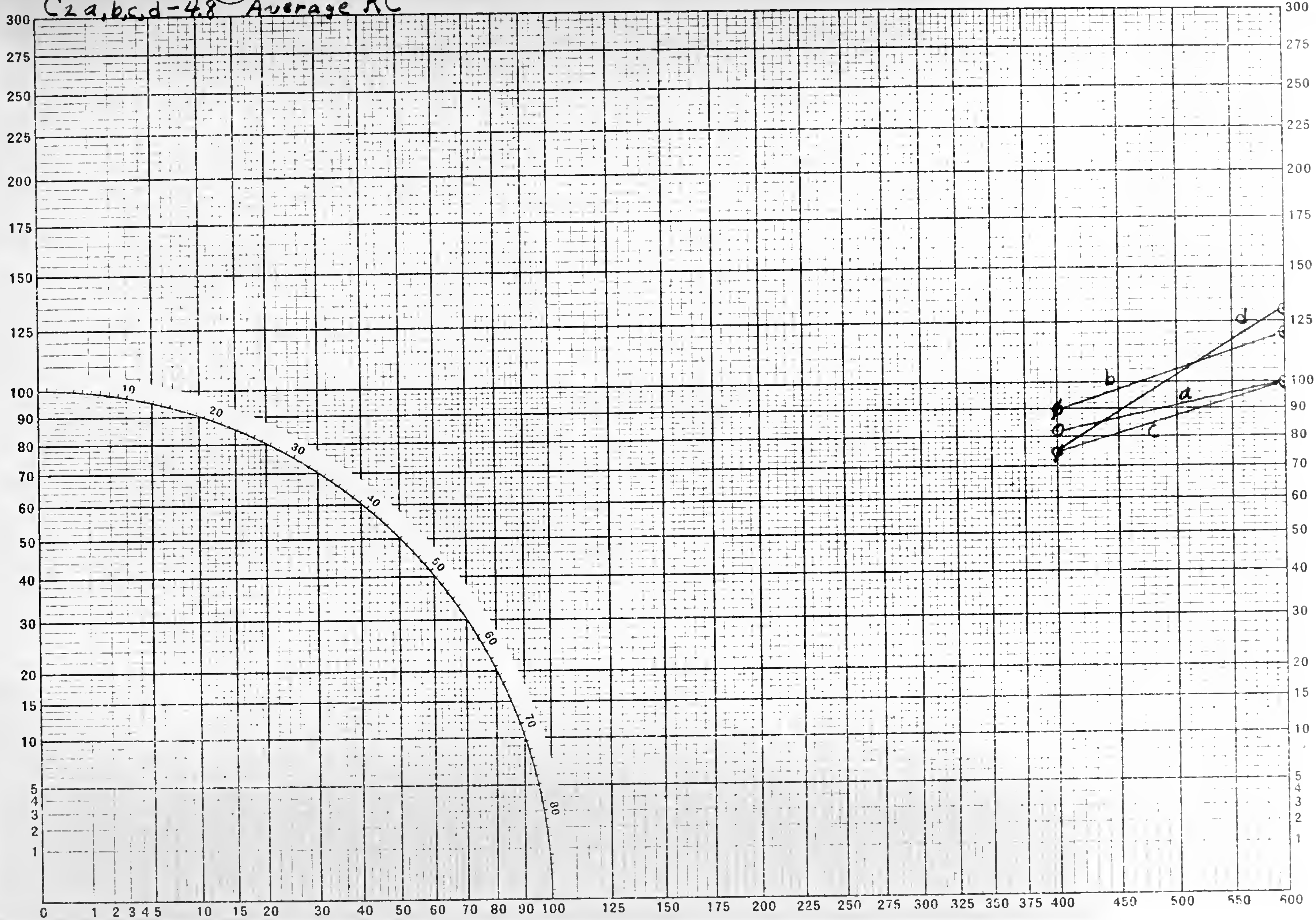

Full Scale
Individual Standard Errors
Tenth Scale
B3 a,b,c,d – 5.8 Average RC
b
c
d

Full Scale

Individual Standard Errors

Tenth Scale

C2 a,b,c,d-48 Average RC

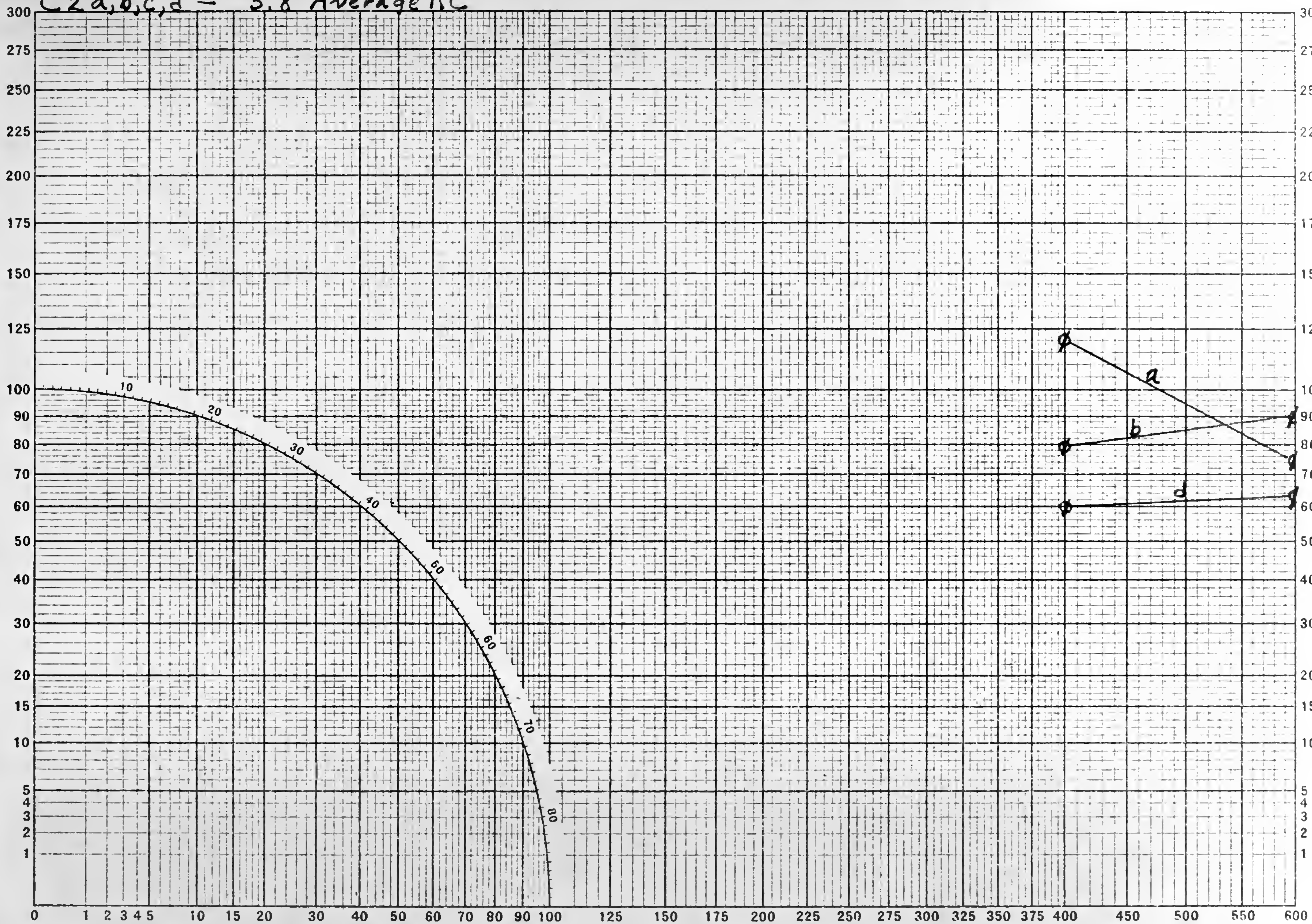


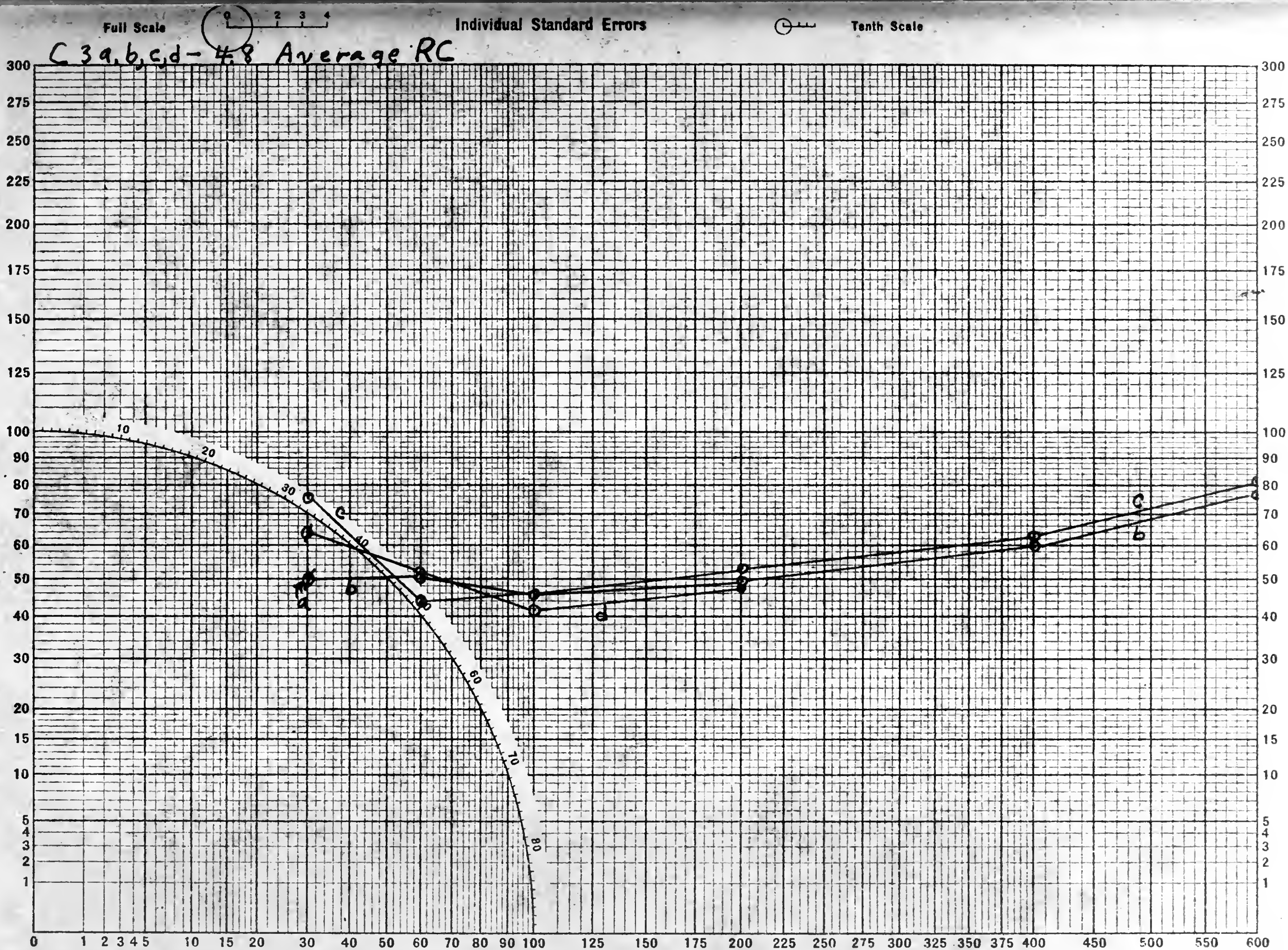
Full Scale

Individual Standard Errors

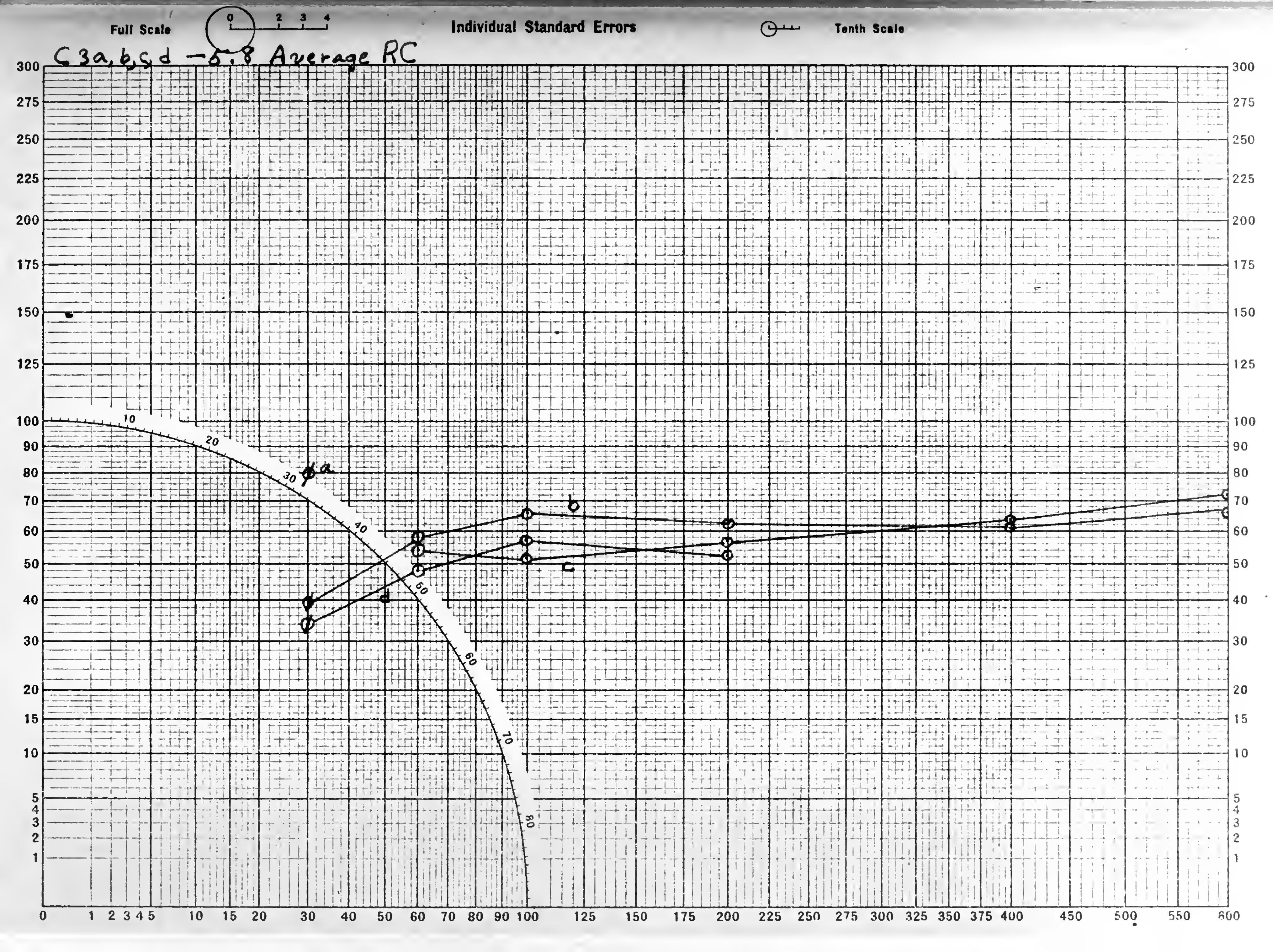
Tenth Scale

C2a,b,c,d – 5.8 Average RC

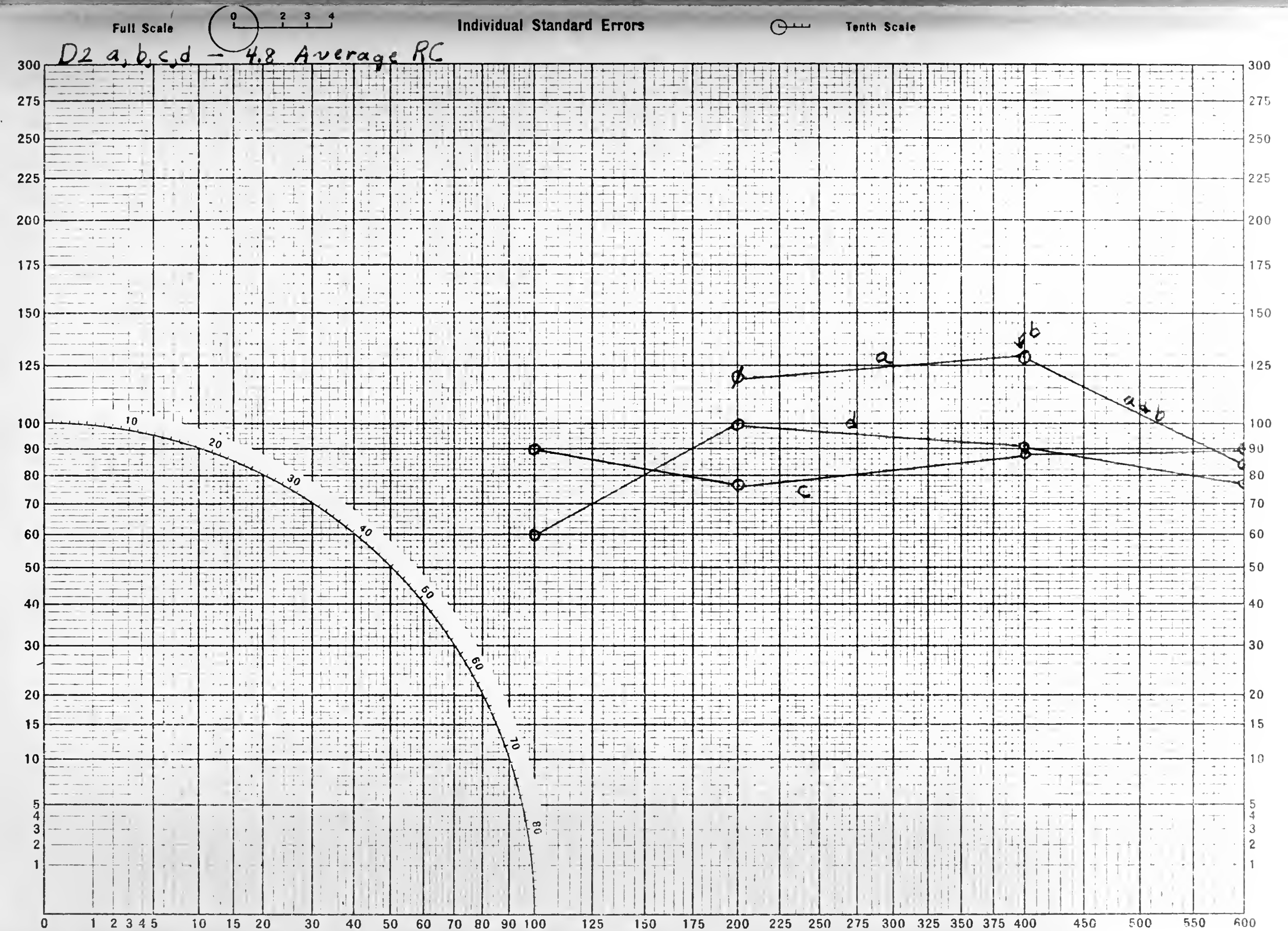




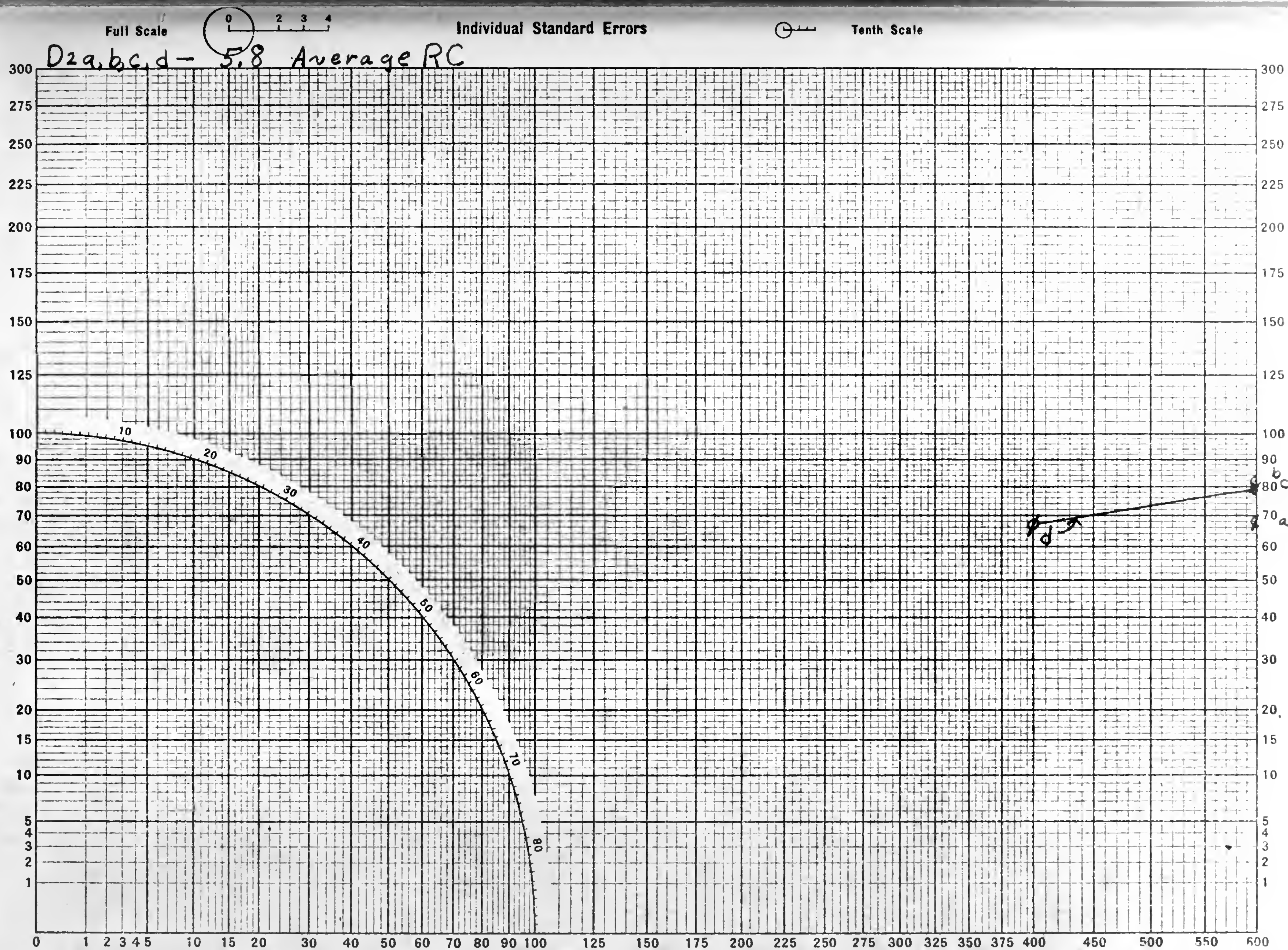
Full Scale
Individual Standard Errors
Tenth Scale
C 3a,b,c,d - 4.8 Average RC



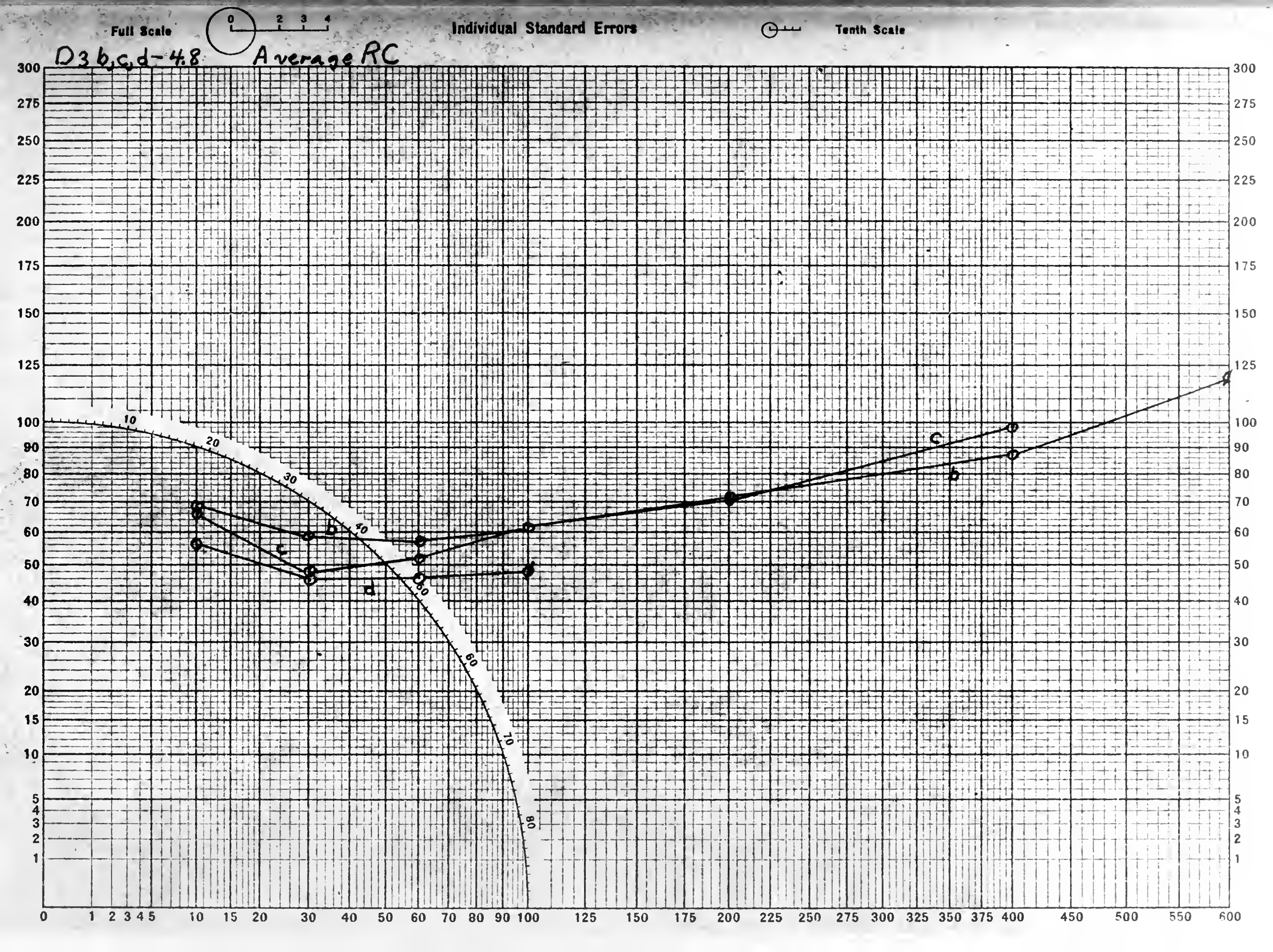
Full Scale
Individual Standard Errors
Tenth Scale
C 3a, b, c, d — 5.8 Average RC
a
b
c
d

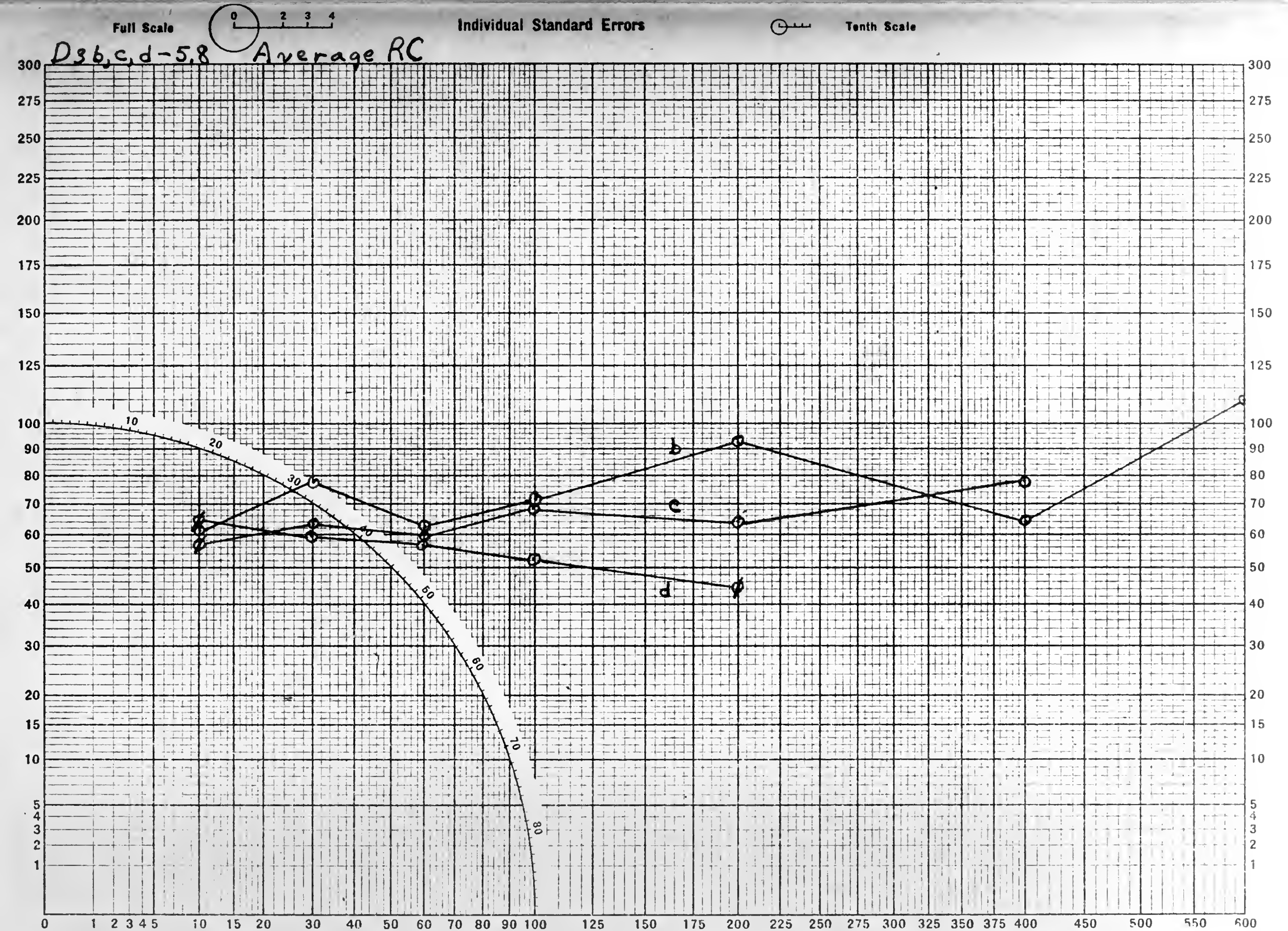


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2 a, b, c, d — 4.8 Average RC
a
b
c
d
a + b



Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2a,b,c,d - 5.8 Average RC
a
b
c
d

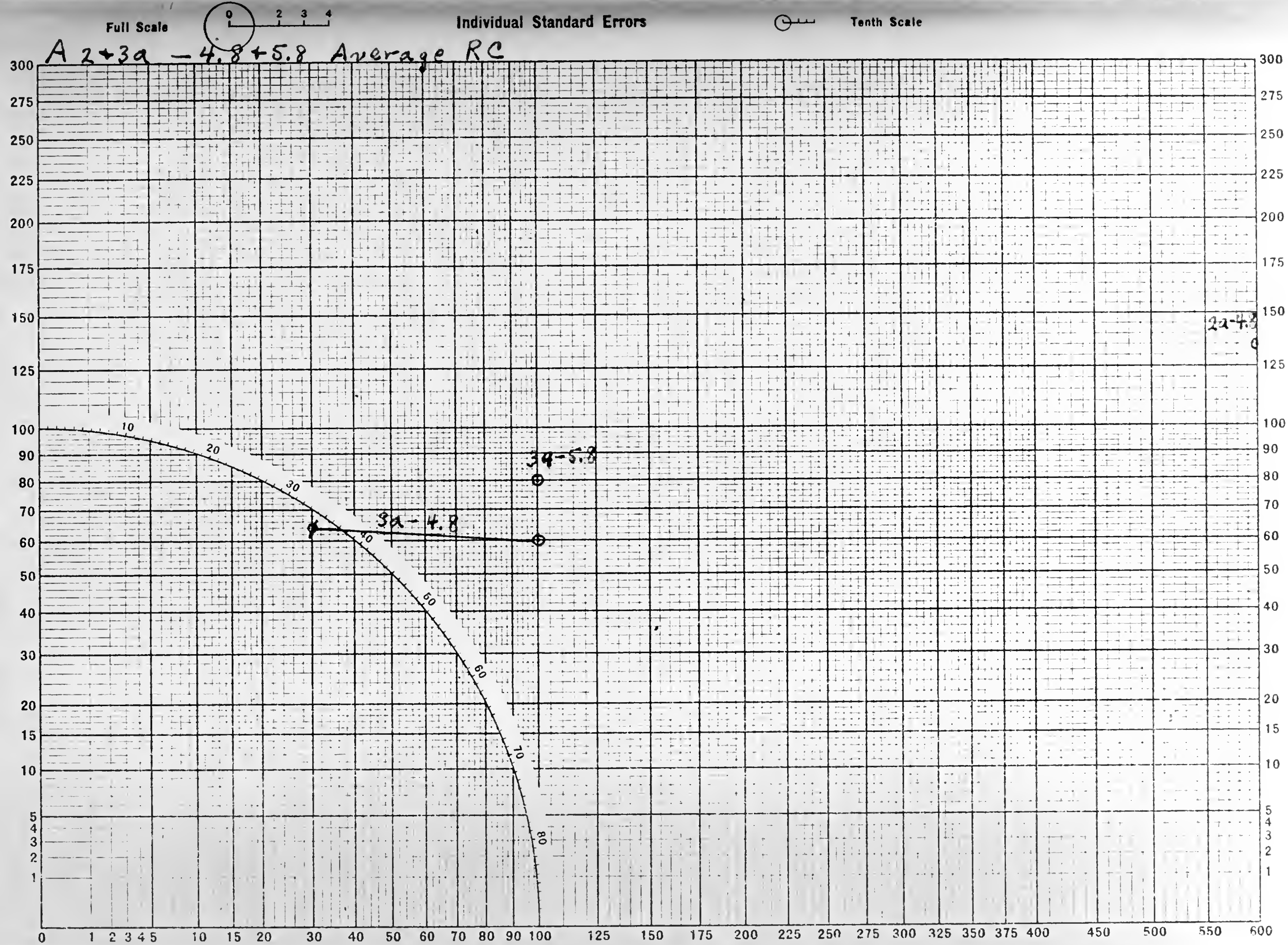

Full Scale
Individual Standard Errors
Tenth Scale
D3 b,c,d-4.8
Average RC
b
c
d
a


Full Scale
Individual Standard Errors
Tenth Scale
D3b,c,d-5,8
Average RC
b
c
d

AVERAGE TIME CONSTANT, COMPARING

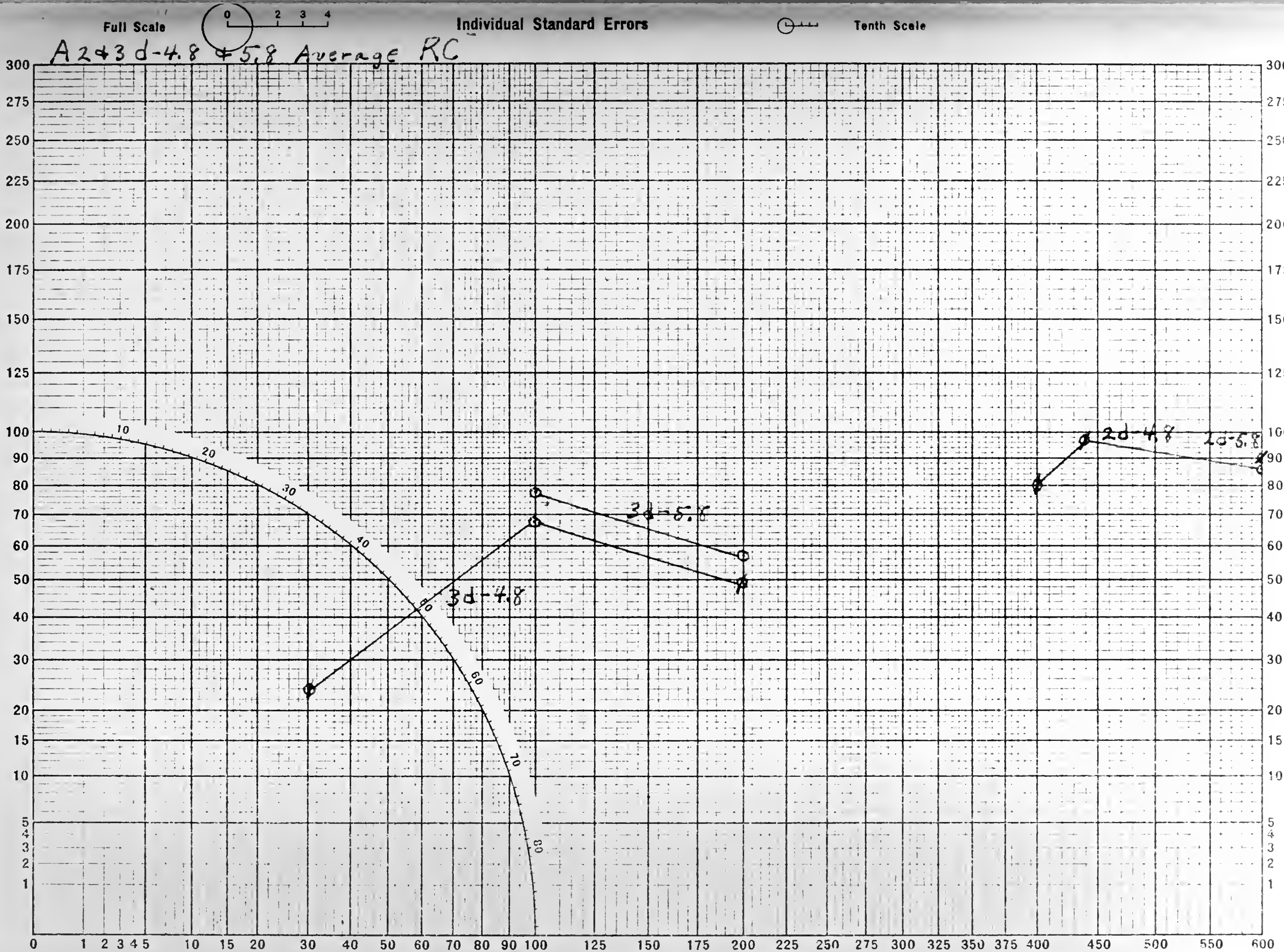
OPERATING CATHODE TEMPERATURE

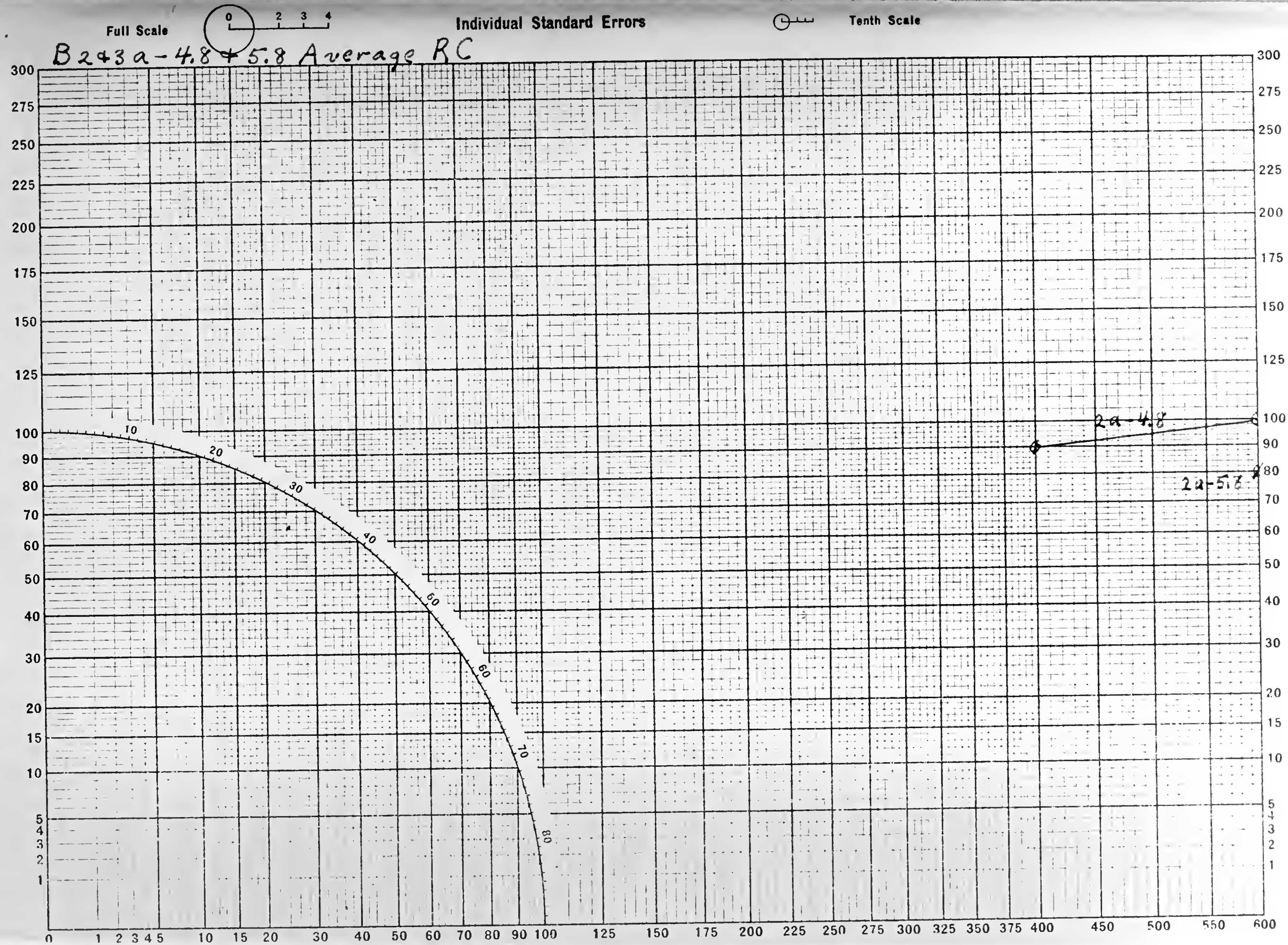
EFFECTS


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2+3a -4.8+5.8 Average RC
3a-5.8
3a-4.8
2a-4.8
10
20
30
40
50
60
70
80

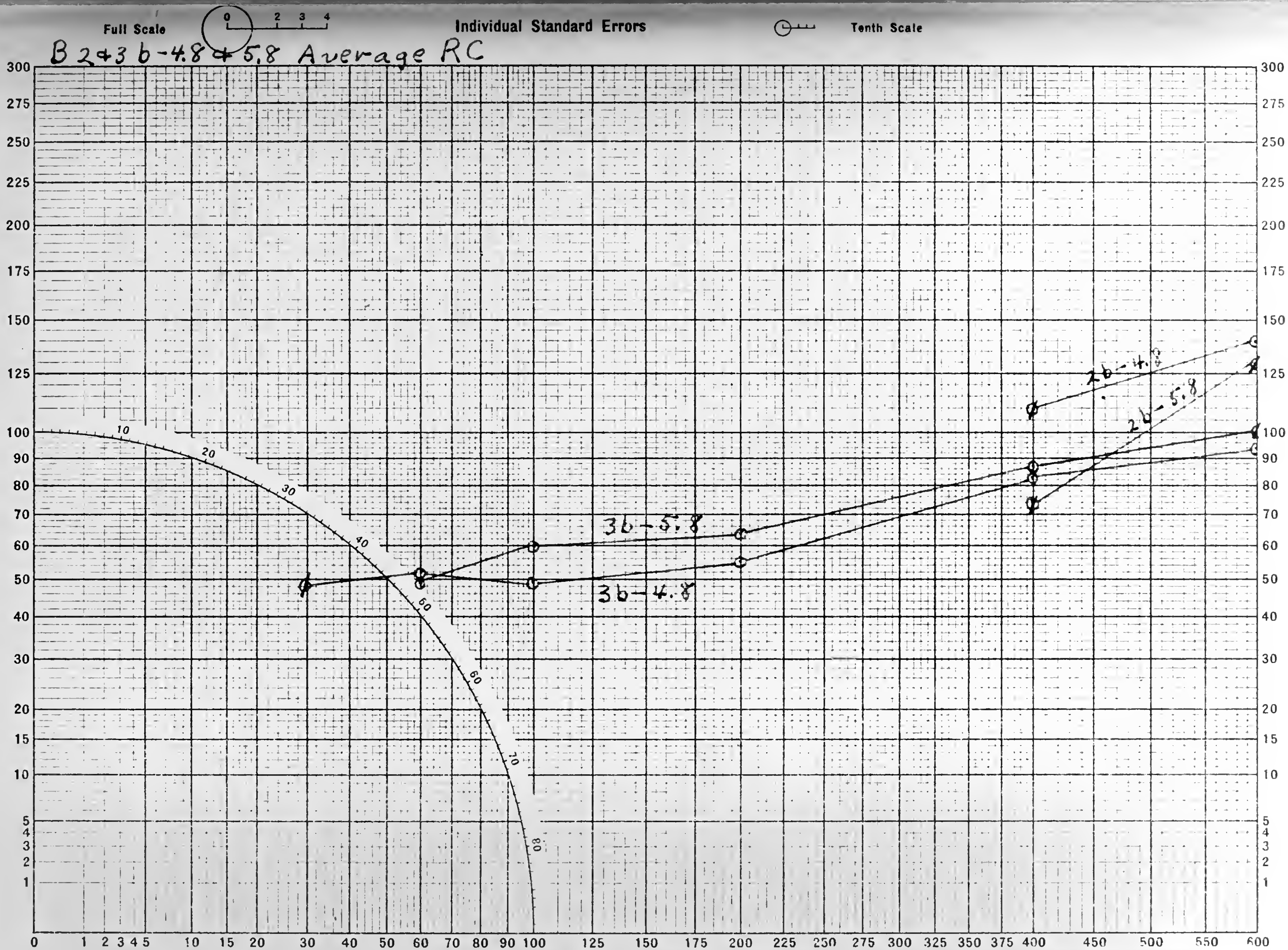
Full Scale
Individual Standard Errors
Tenth Scale
A 2+3 b – 4.8 + 5.8 Average RC
2b – 4.8
3b – 5.8
3b – 4.8
2b – 5.8

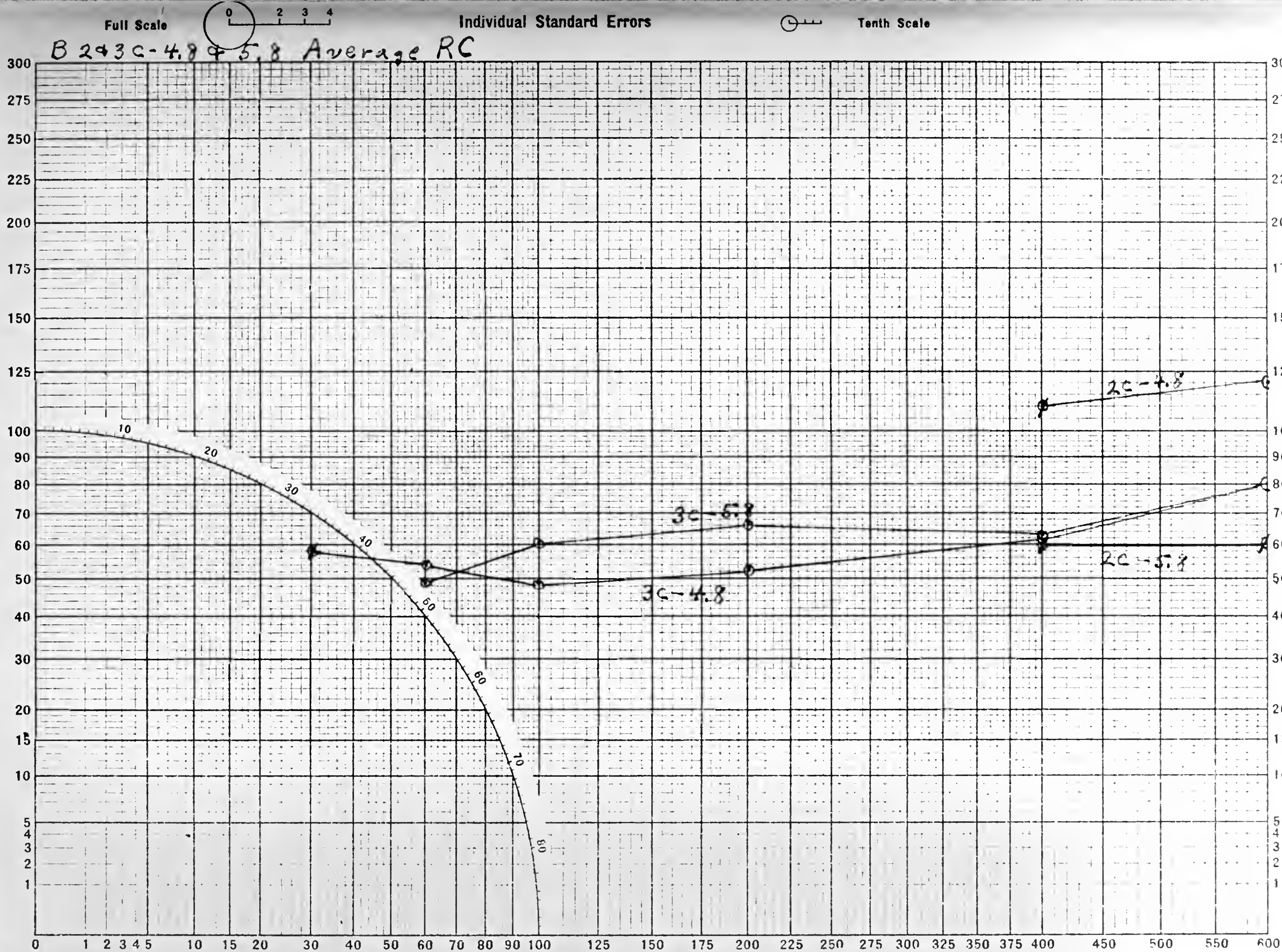
Full Scale
Individual Standard Errors
Tenth Scale
A 2+3C-4.8+5.8 Average RC
3C-4.8
3C-5.8
2C-4.8
2C-5.8


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A 2+3 d-4.8 + 5.8 Average RC
3d-5.8
3d-4.8
2d-4.8
2d-5.8

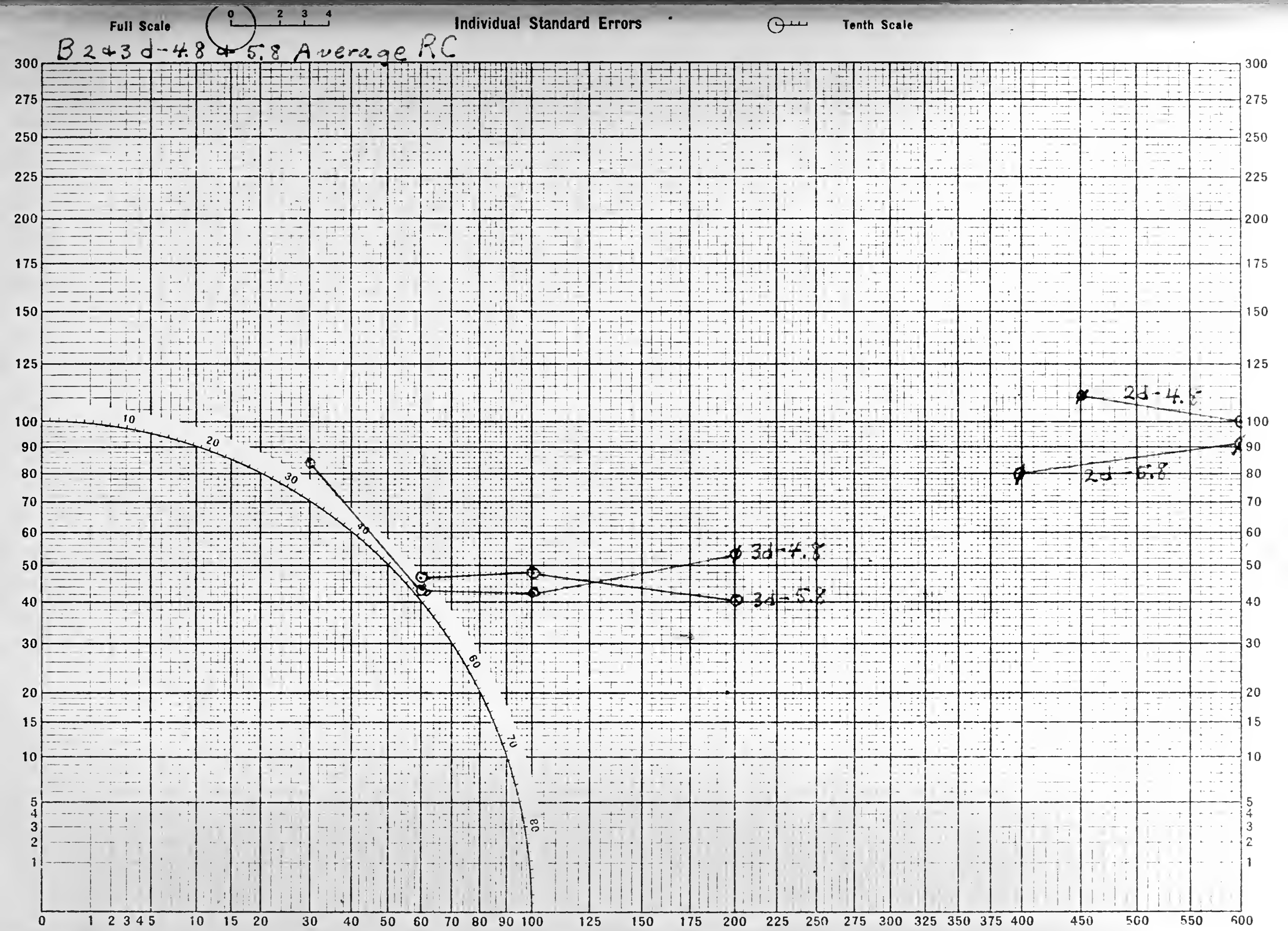


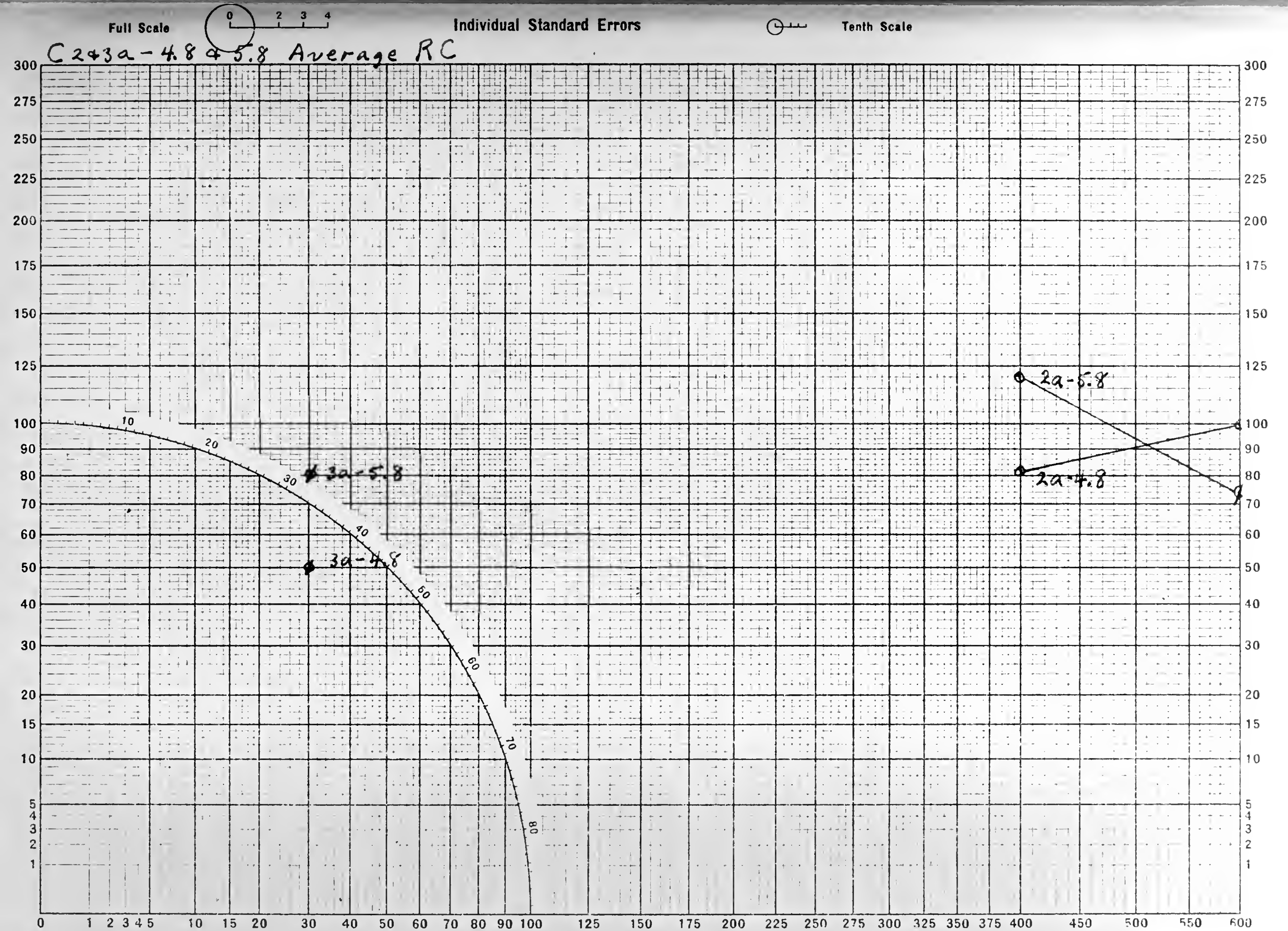
Full Scale
Individual Standard Errors
Tenth Scale
B 2+3a - 4.8 + 5.8 Average RC
2a-4.8
2a-5.8


Full Scale
Individual Standard Errors
Tenth Scale
B 2+3 b-4.8 + 5.8 Average RC
3b-5.8
3b-4.8
2b-4.8
2b-5.8

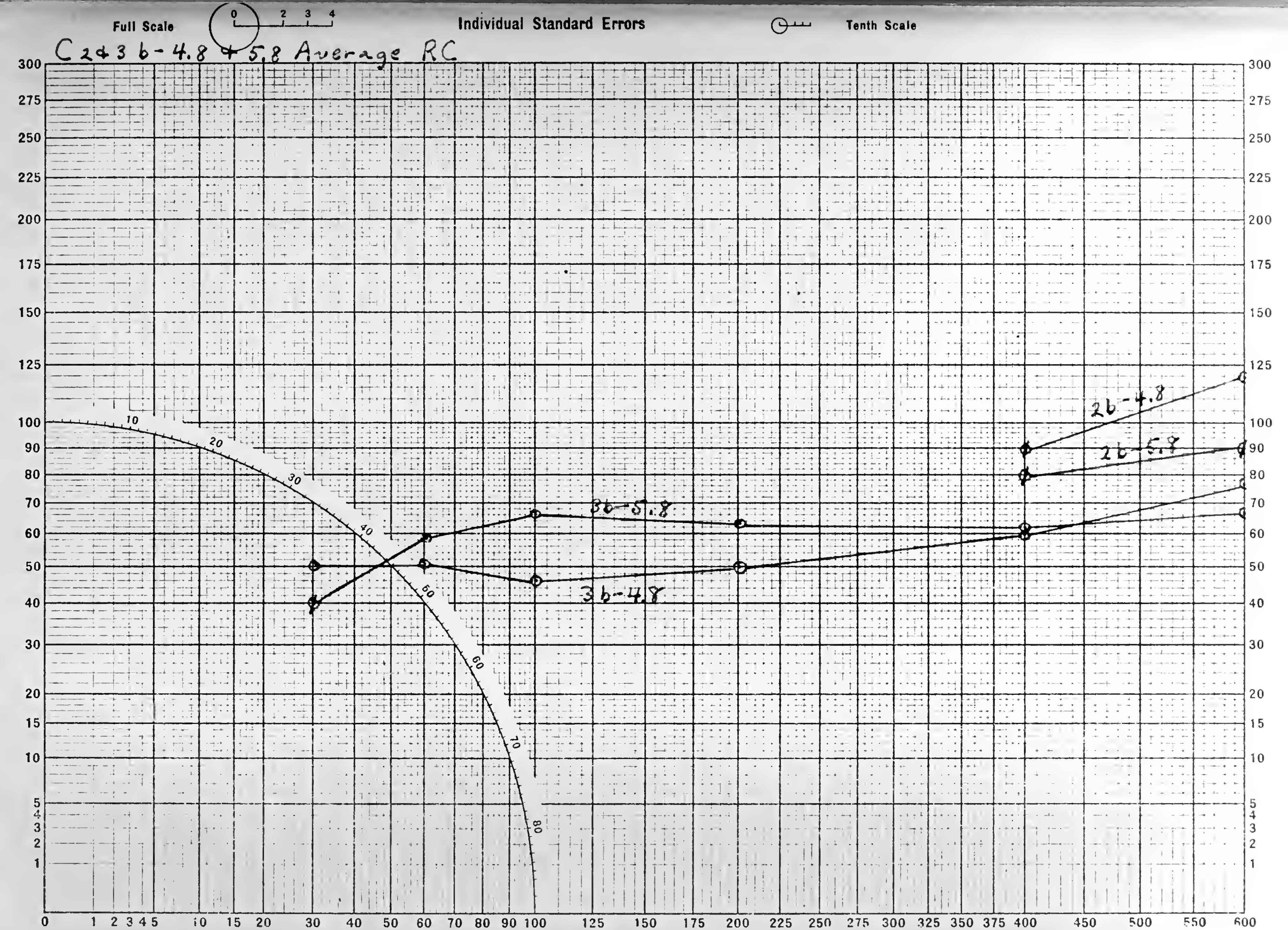


Full Scale
Individual Standard Errors
Tenth Scale
B 2+3C-4.8 + 5.8 Average RC
2C-4.8
2C-5.8
3C-5.8
3C-4.8


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
B 2+3 d-4.8 + 5.8 Average RC
2d-4.8
2d-5.8
3d-4.8
3d-5.8

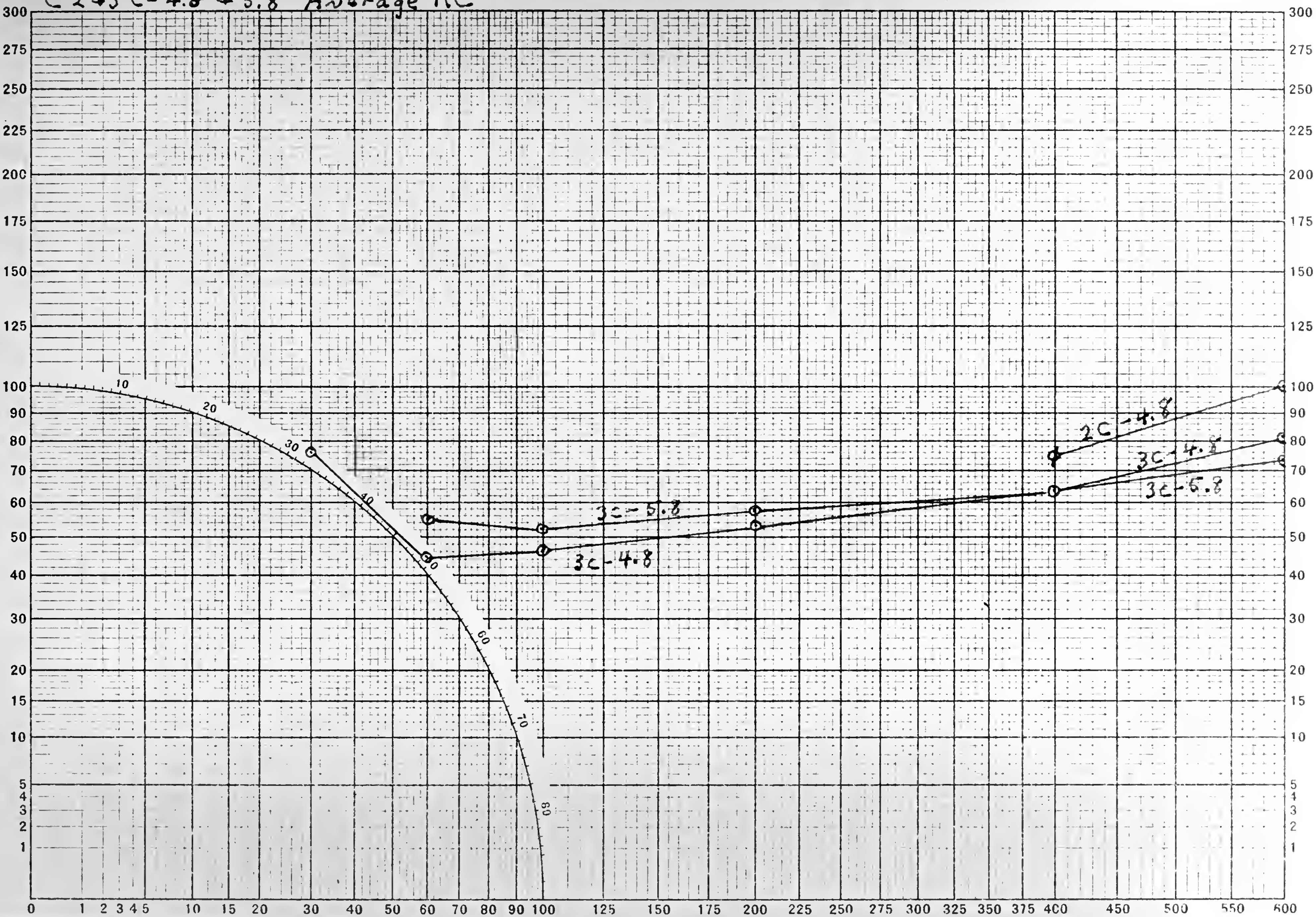

Full Scale
Individual Standard Errors
Tenth Scale
C 2 & 3a - 4.8 & 5.8 Average RC
3a-5.8
3a-4.8
2a-5.8
2a-4.8

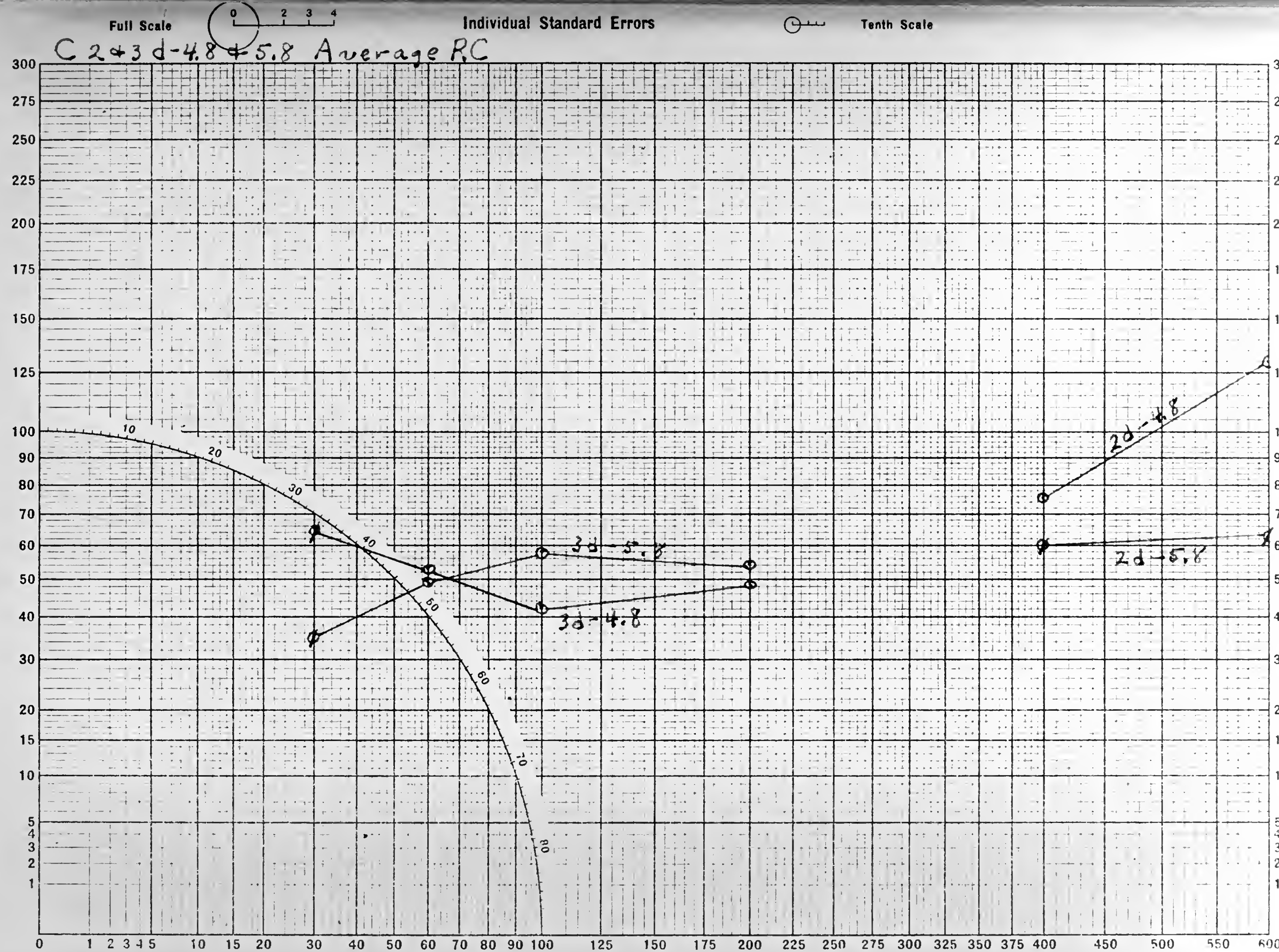
C 2+3 b-4.8 + 5.8 Average RC



Full Scale   Individual Standard Errors   Tenth Scale

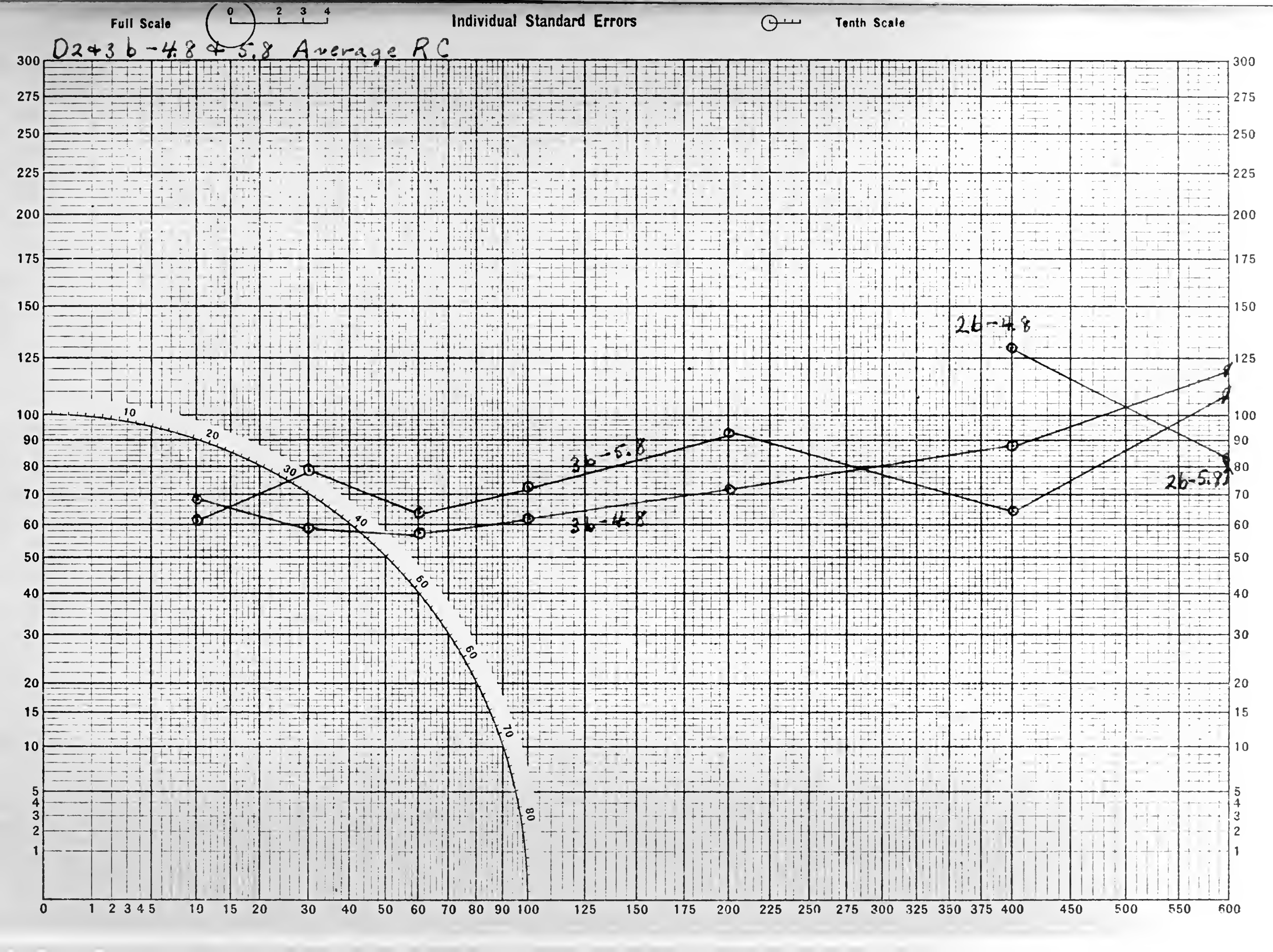
C 2 + 3 c - 4.8 + 5.8 Average RC

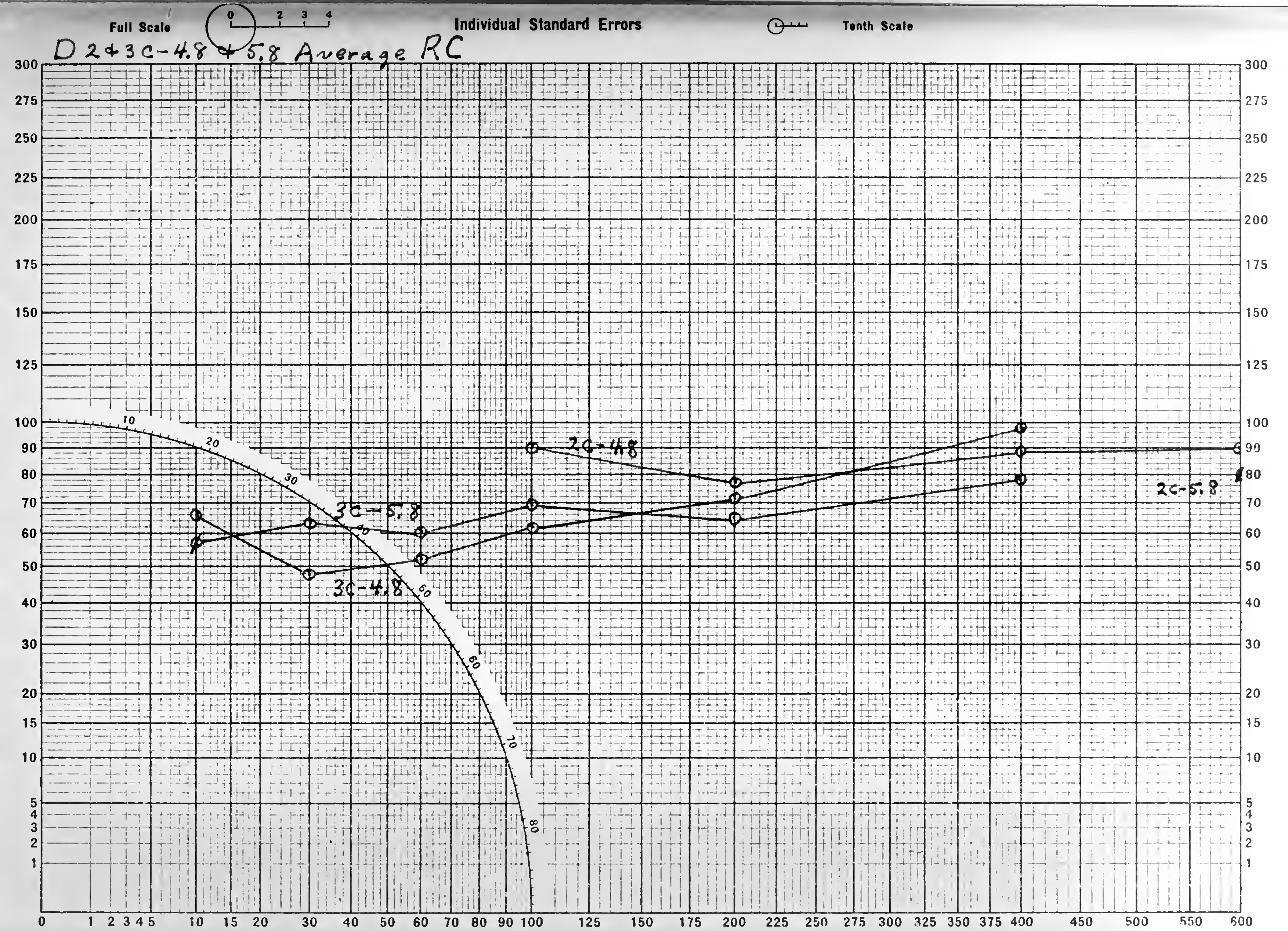




Full Scale
Individual Standard Errors
Tenth Scale
C 2+3 d-4.8 + 5.8 Average RC
3d-5.8
3d-4.8
2d-4.8
2d-5.8


Full Scale
Individual Standard Errors
Tenth Scale
D 2a — 4.8 + 5.8 Average RC
2a-4.8
2a-5.8


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
D2+3b-4.8 + 5.8 Average RC
2b-4.8
2b-5.8
3b-5.8
3b-4.8

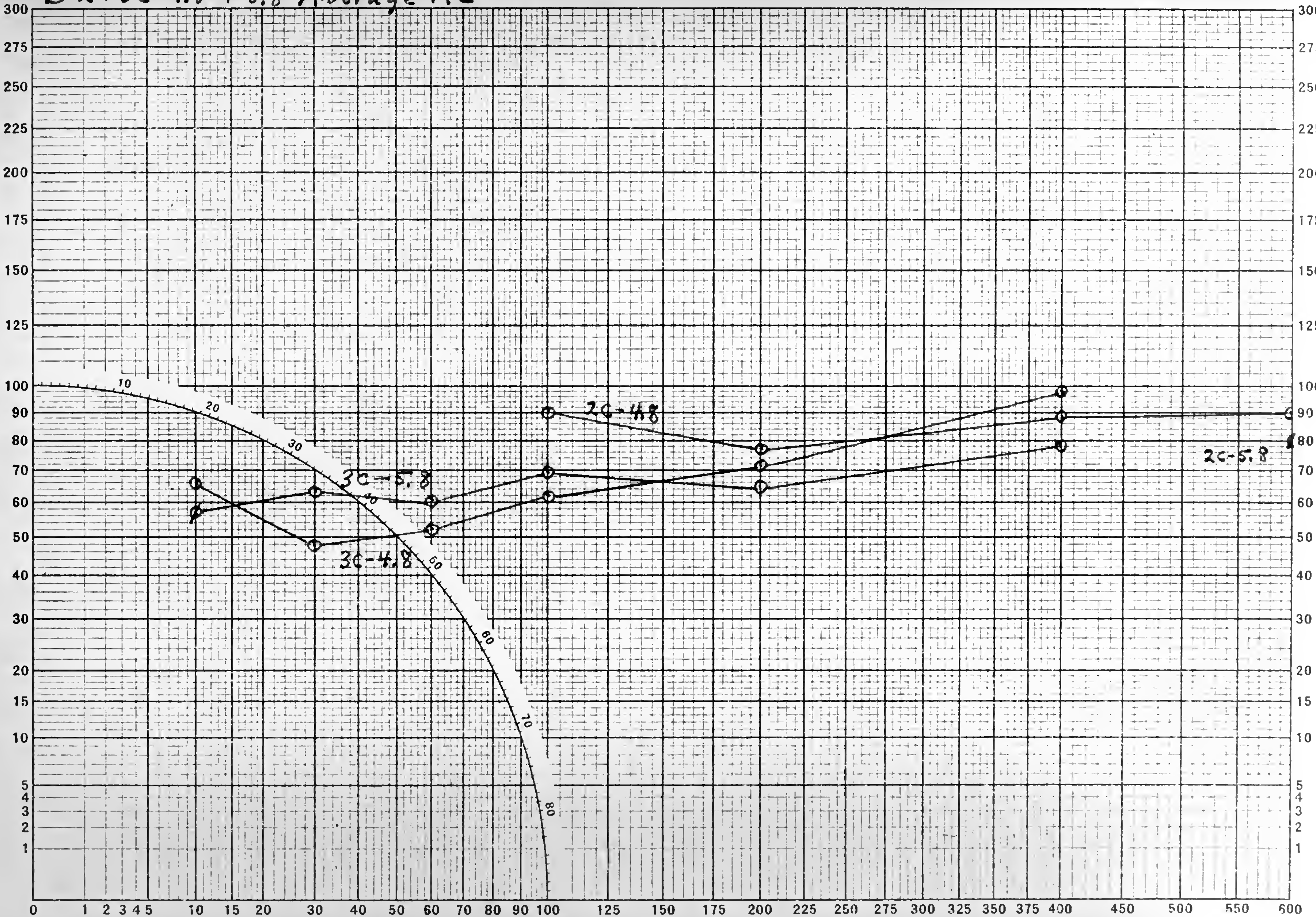

Full Scale
Individual Standard Errors
Tenth Scale
D 2+3C-4.8 + 5.8 Average RC
2C-4.8
2C-5.8
3C-5.8
3C-4.8

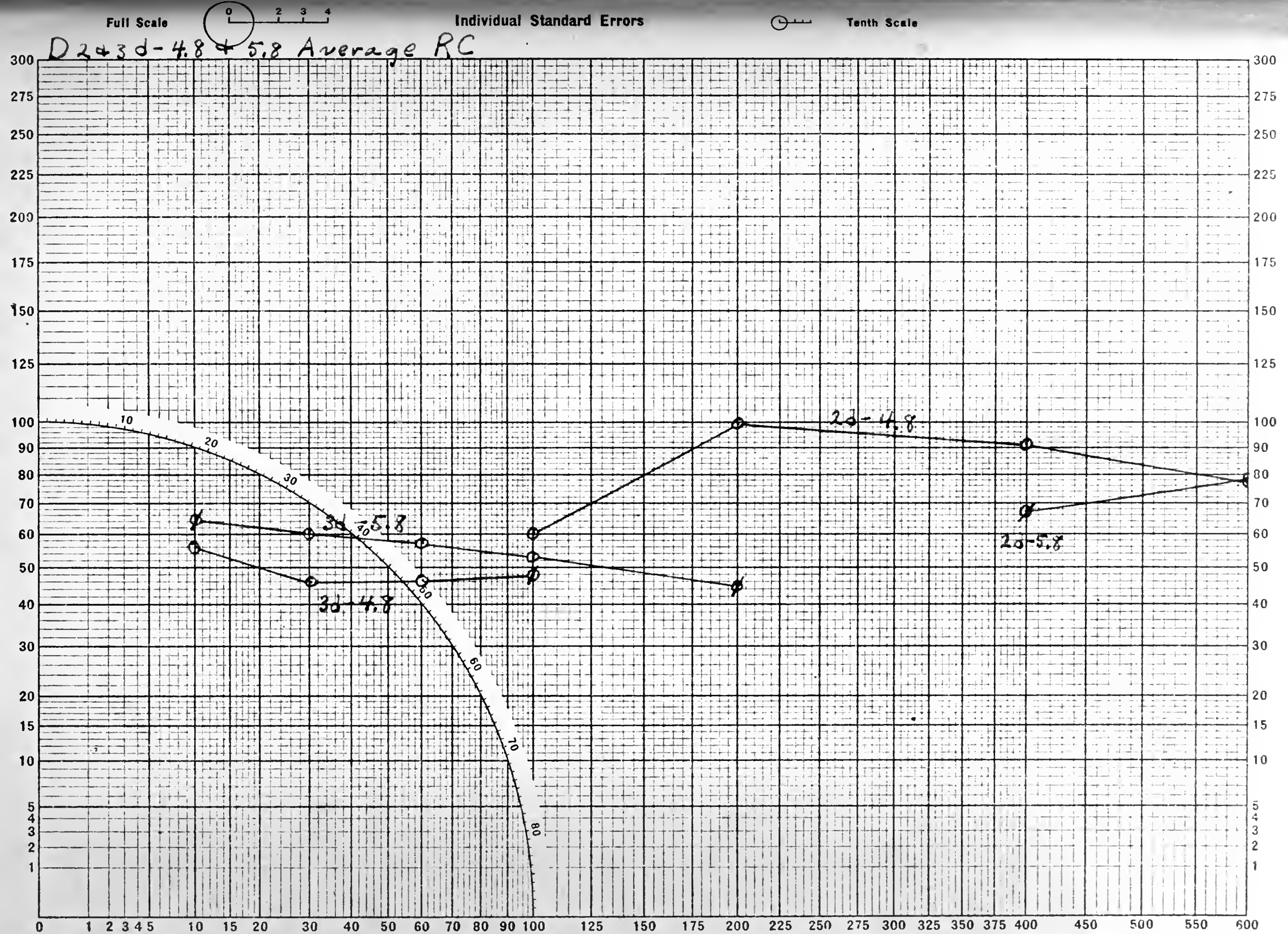
Full Scale

Individual Standard Errors

Tenth Scale

D 2+3C-4.8 + 5.8 Average RC



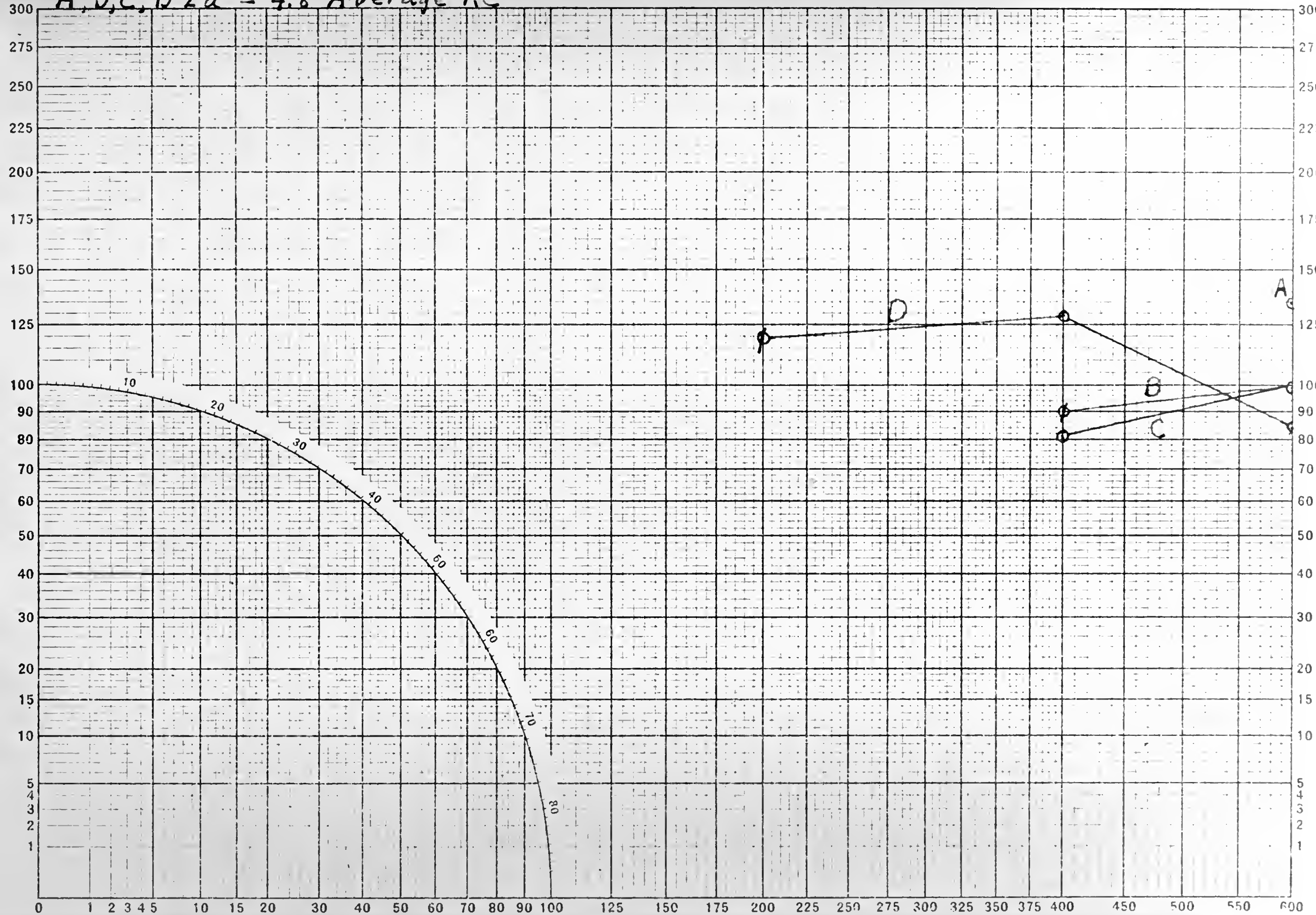

Full Scale
Individual Standard Errors
Tenth Scale
D 2 + 3 d - 4.8 + 5.8 Average RC
2d - 4.8
2d - 5.8
3d - 5.8
3d - 4.8

AVERAGE TIME CONSTANT, COMPARING

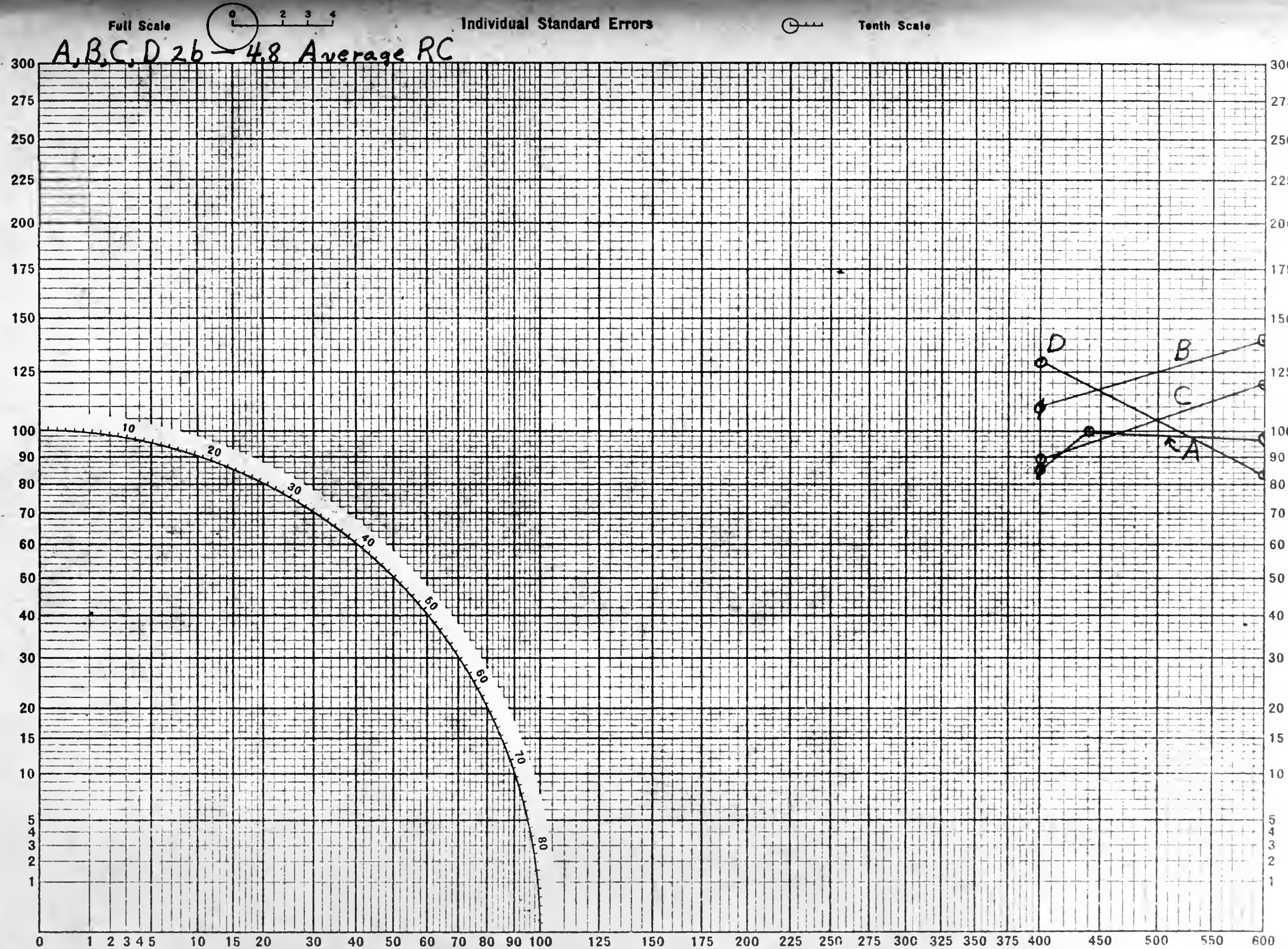
PREVIOUS LIFE EXPERIENCE EFFECTS

Full Scale · Individual Standard Errors · Tenth Scale

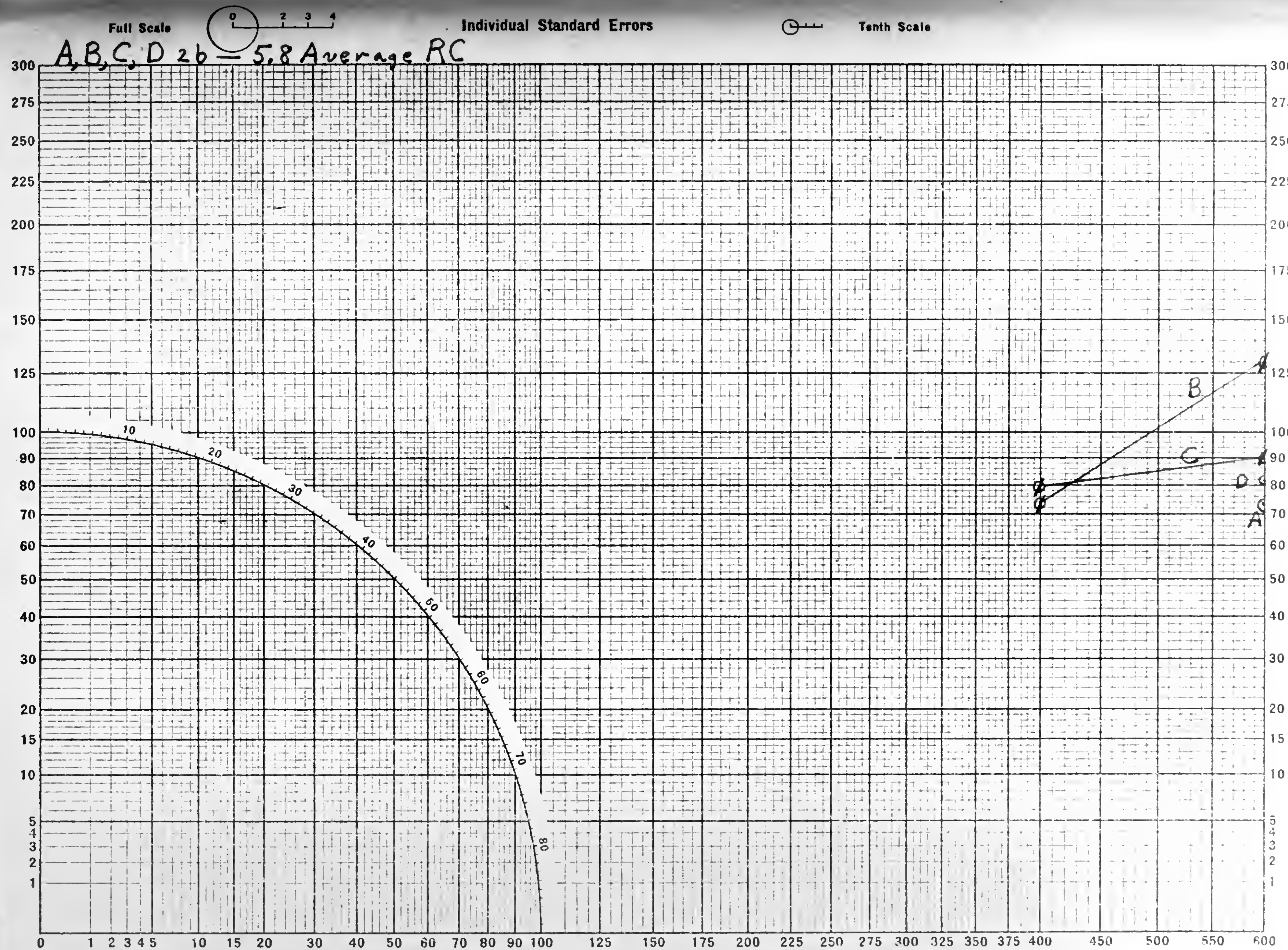
A, B, C, D 2a - 4.8 Average RC



Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 2a — 5.8 Average RC
C
B
D



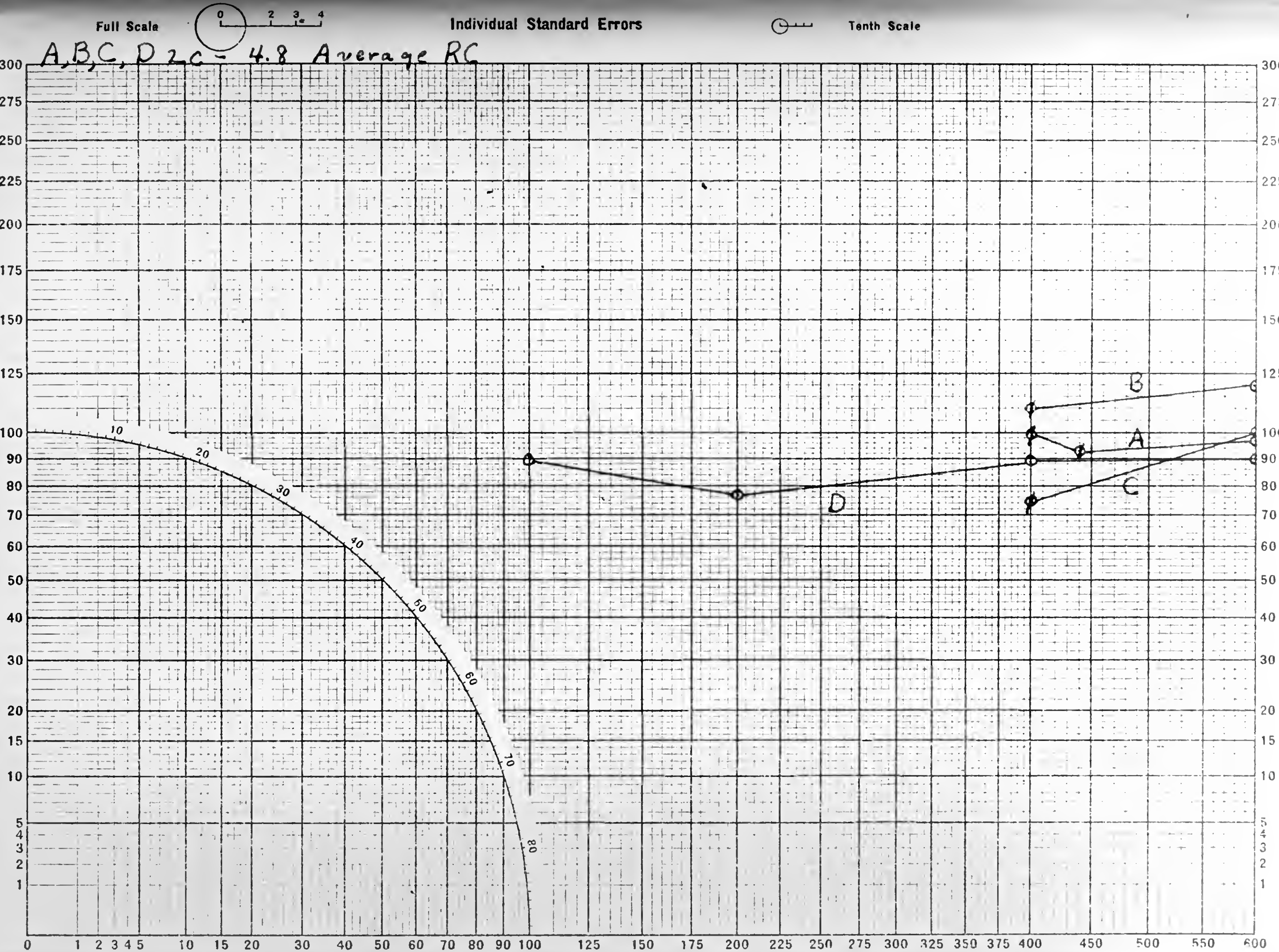
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A,B,C,D 2b — 4.8 Average RC
A
B
C
D
300 275 250 225 200 175 150 125 100 90 80 70 60 50 40 30 20 15 10 5 4 3 2 1
0 1 2 3 4 5 10 15 20 30 40 50 60 70 80 90 100 125 150 175 200 225 250 275 300 325 350 375 400 450 500 550 600
10 20 30 40 50 60 70 80

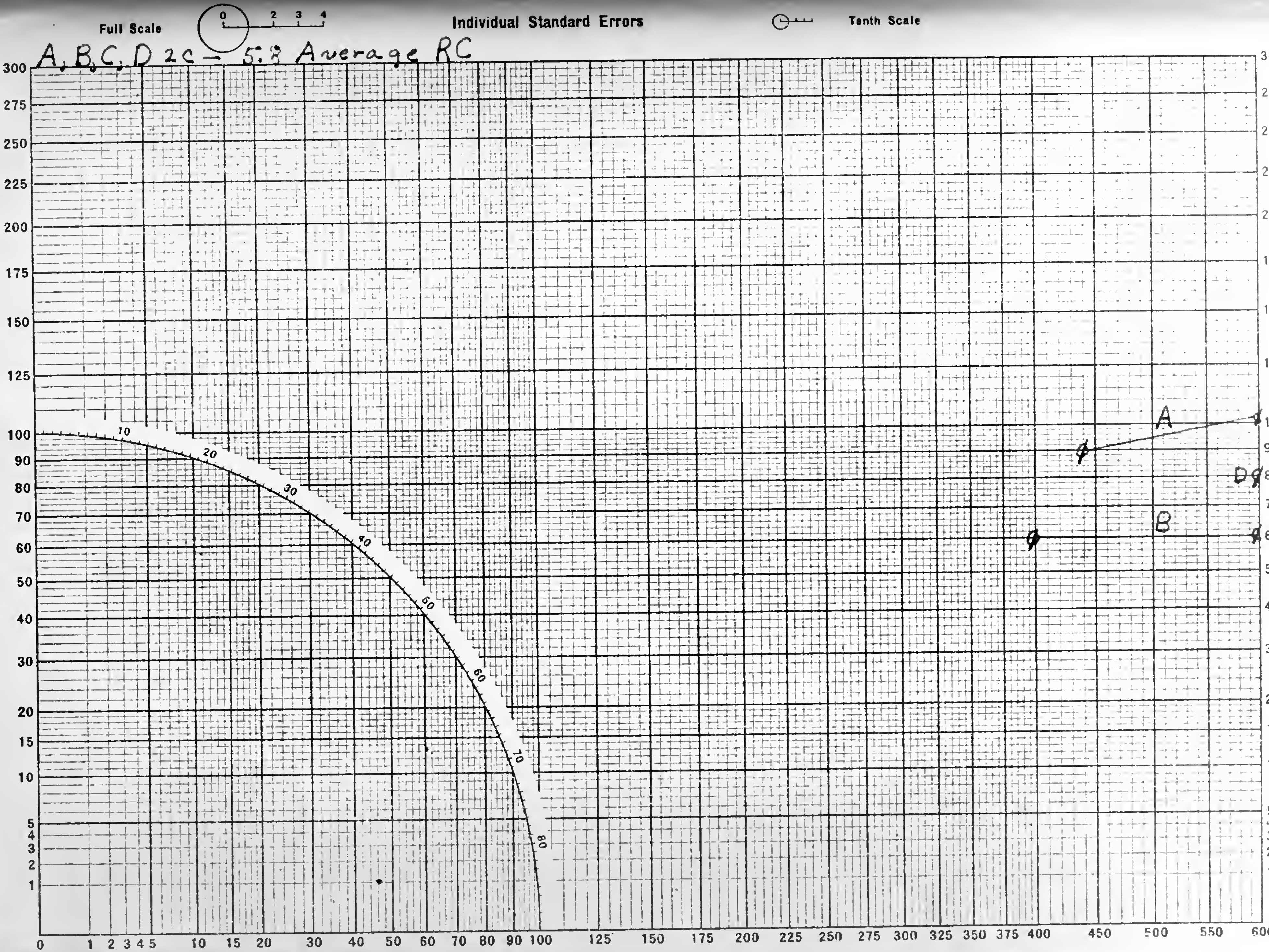


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A, B, C, D 2b — 5.8 Average RC
B
C
D
A

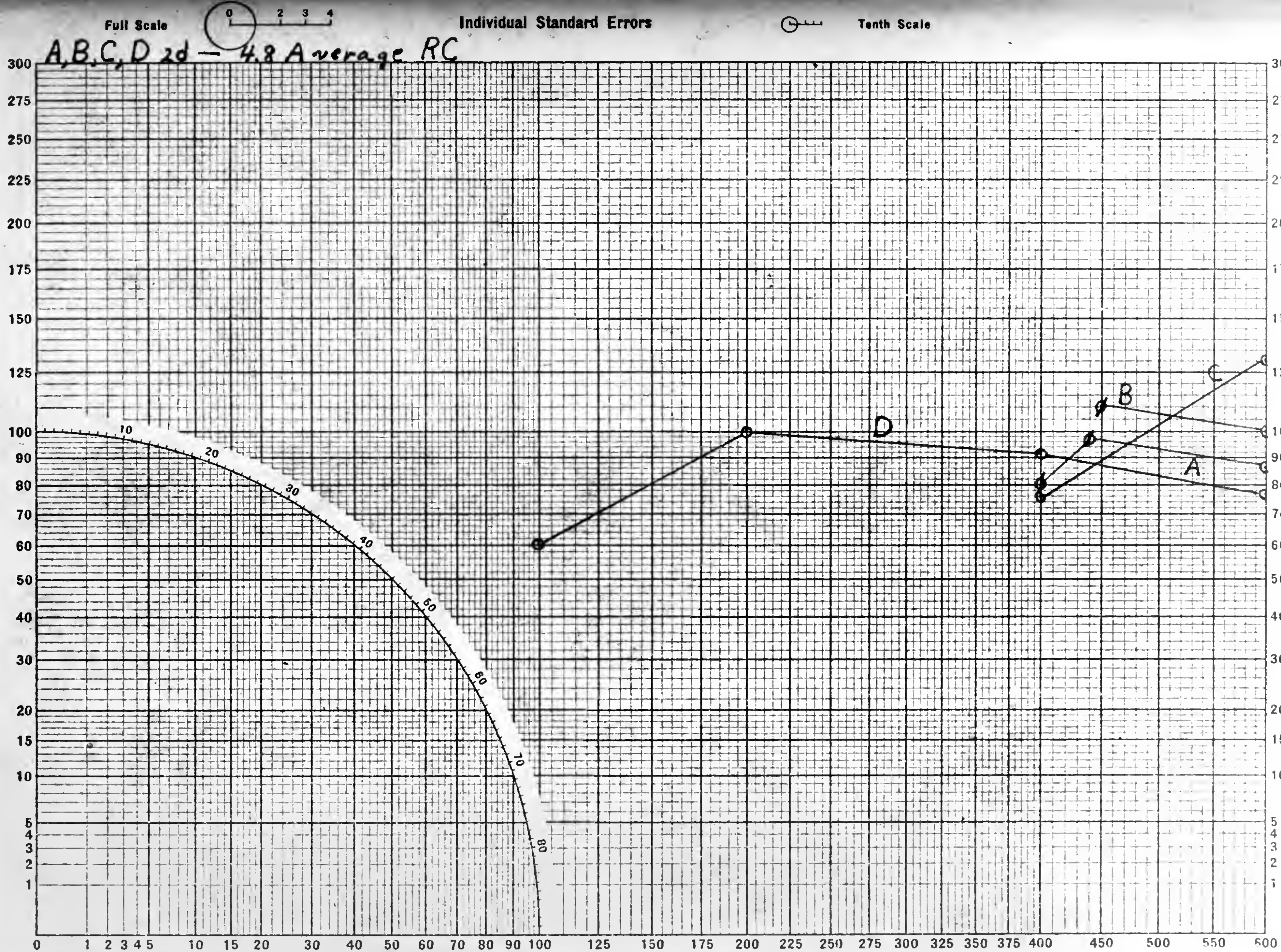
Individual Standard Errors

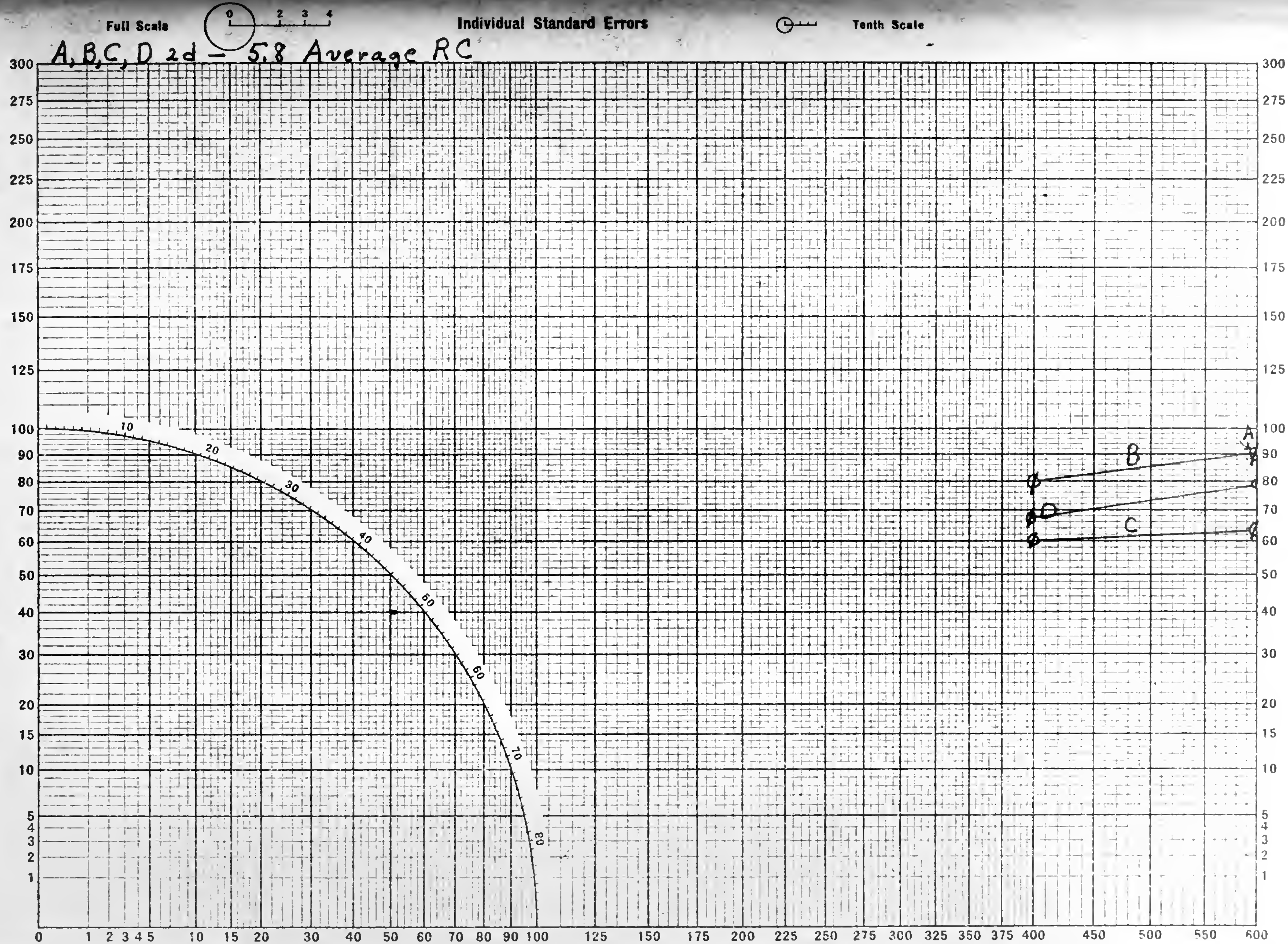
A, B, C, D 2 c - 4.8 Average RC





Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 2c – 5.8 Average RC
A
B
D


Full Scale
Individual Standard Errors
Tenth Scale
A,B,C,D 2d — 4.8 Average RC
A
B
C
D



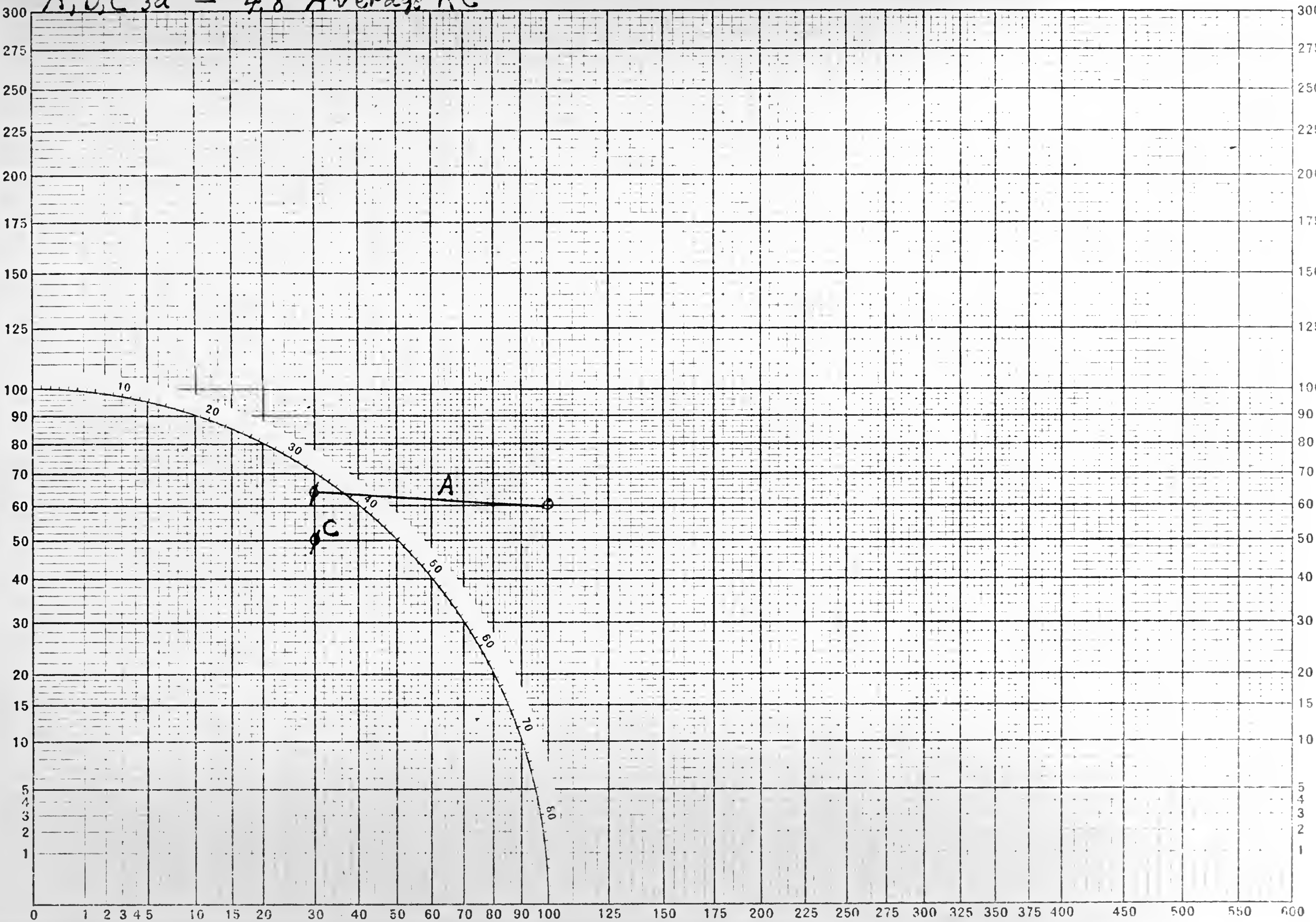
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 2d — 5.8 Average RC
A
B
C
D

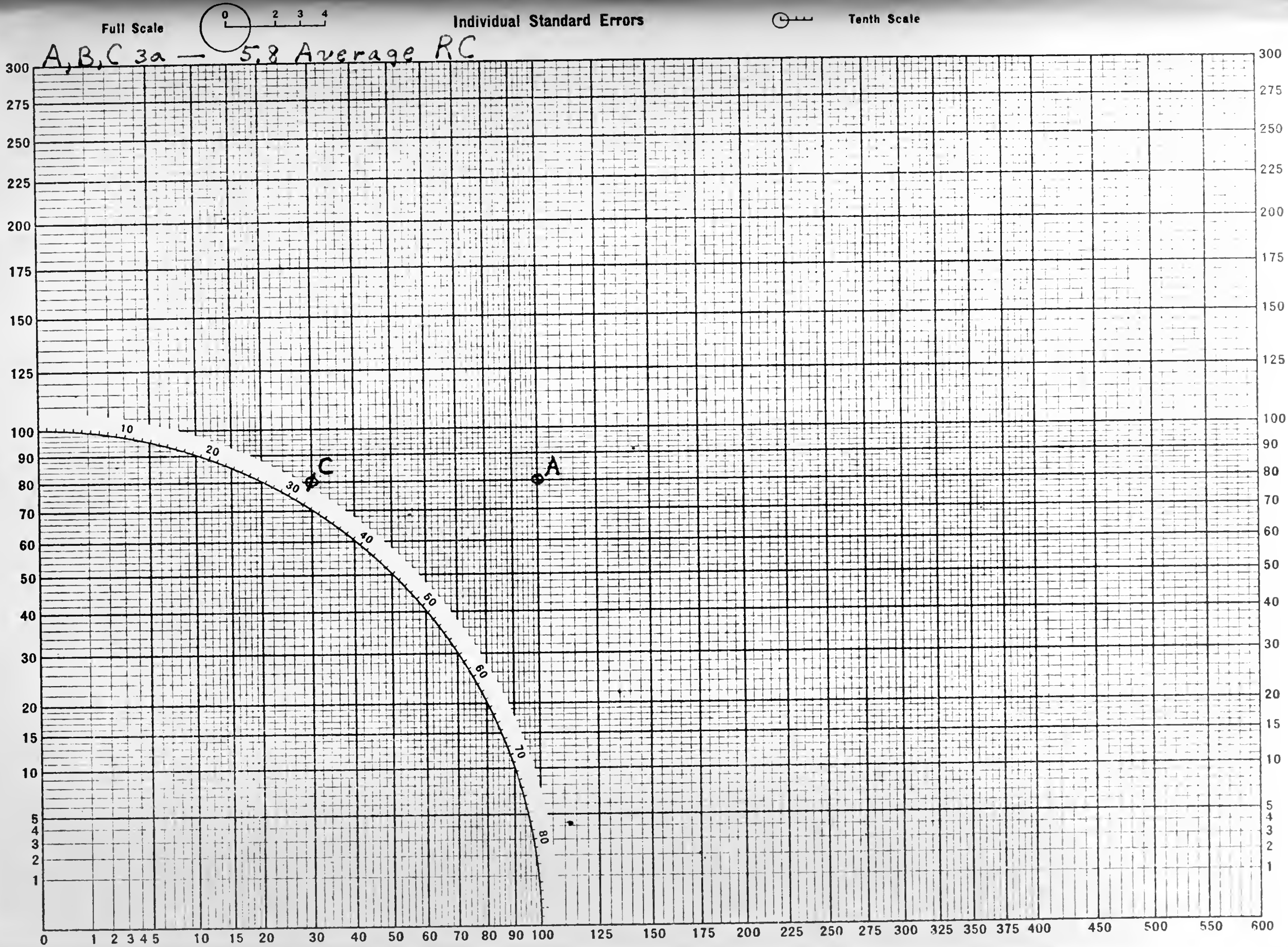
Full Scale

Individual Standard Errors

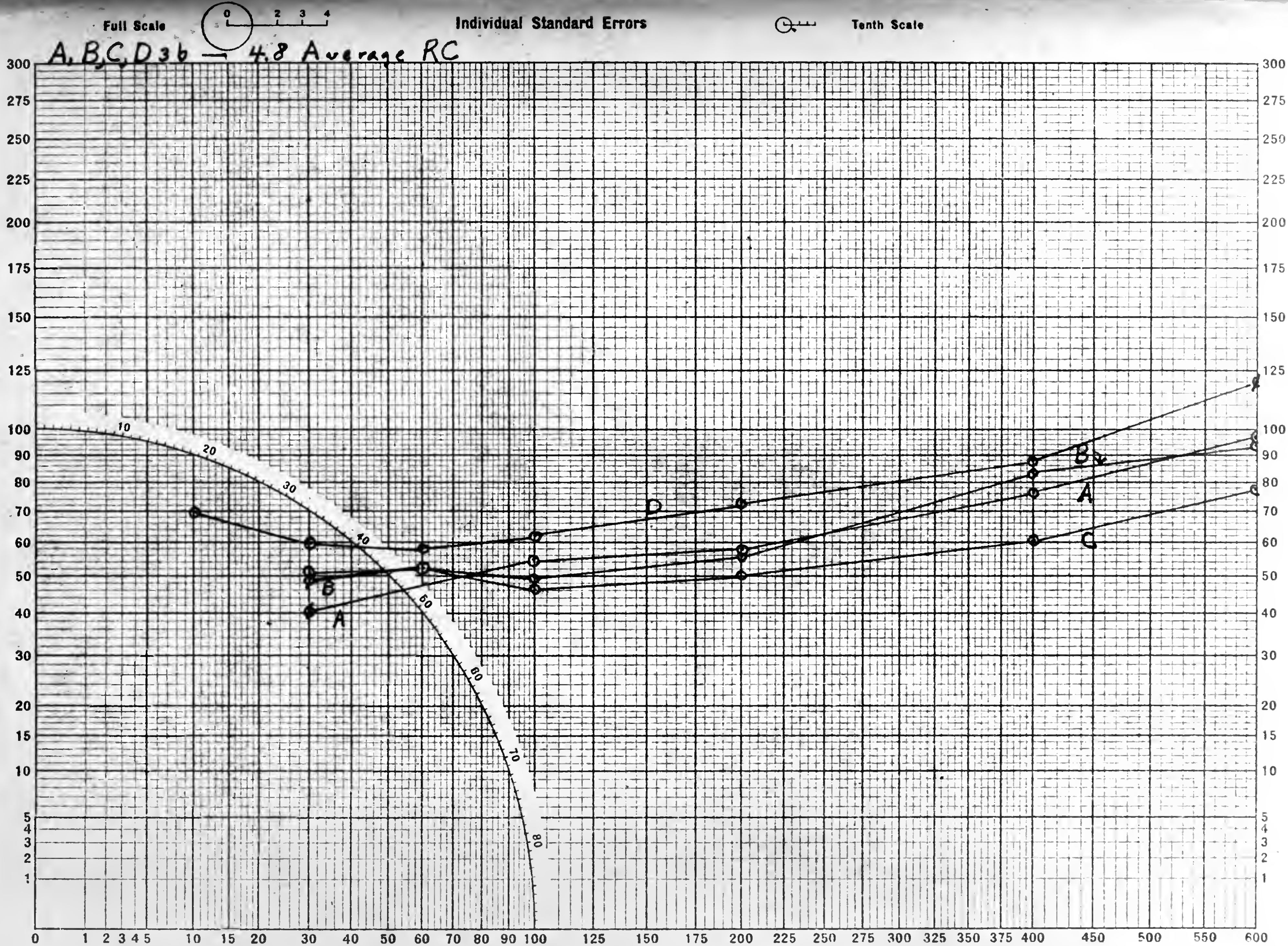
Tenth Scale

A, B, C 3a — 4.8 Average RC

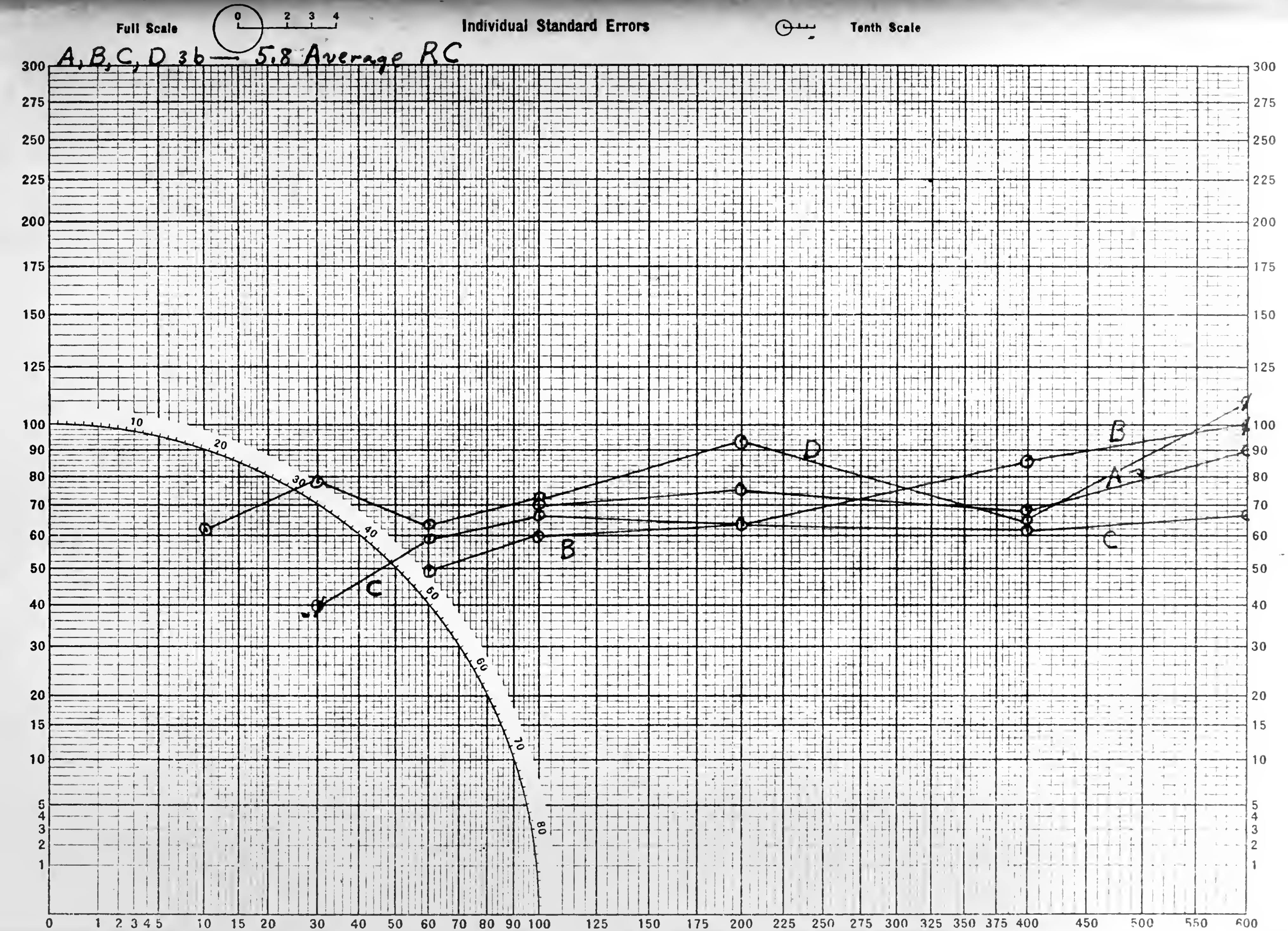




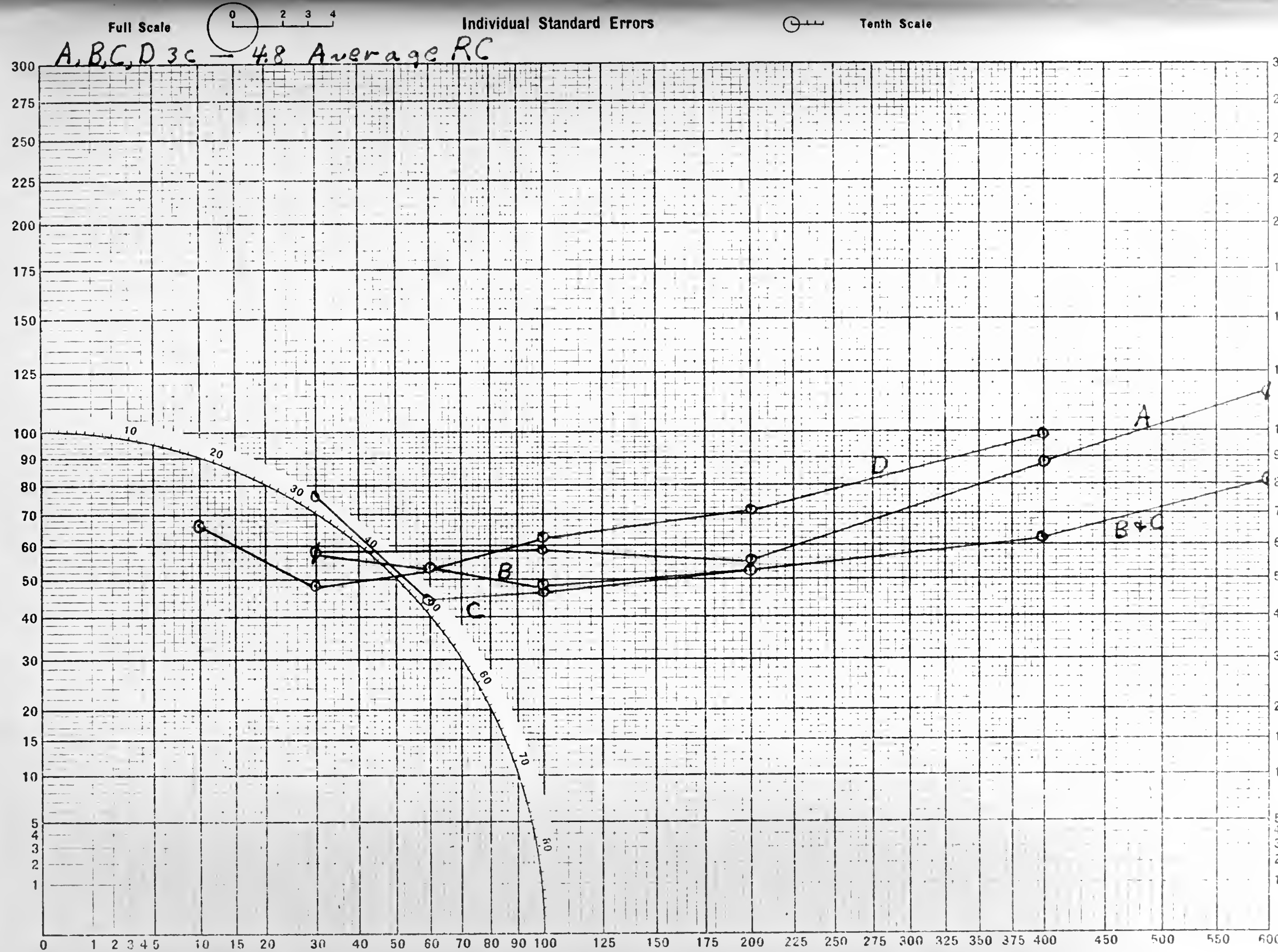
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C 3a — 5.8 Average RC
A
C



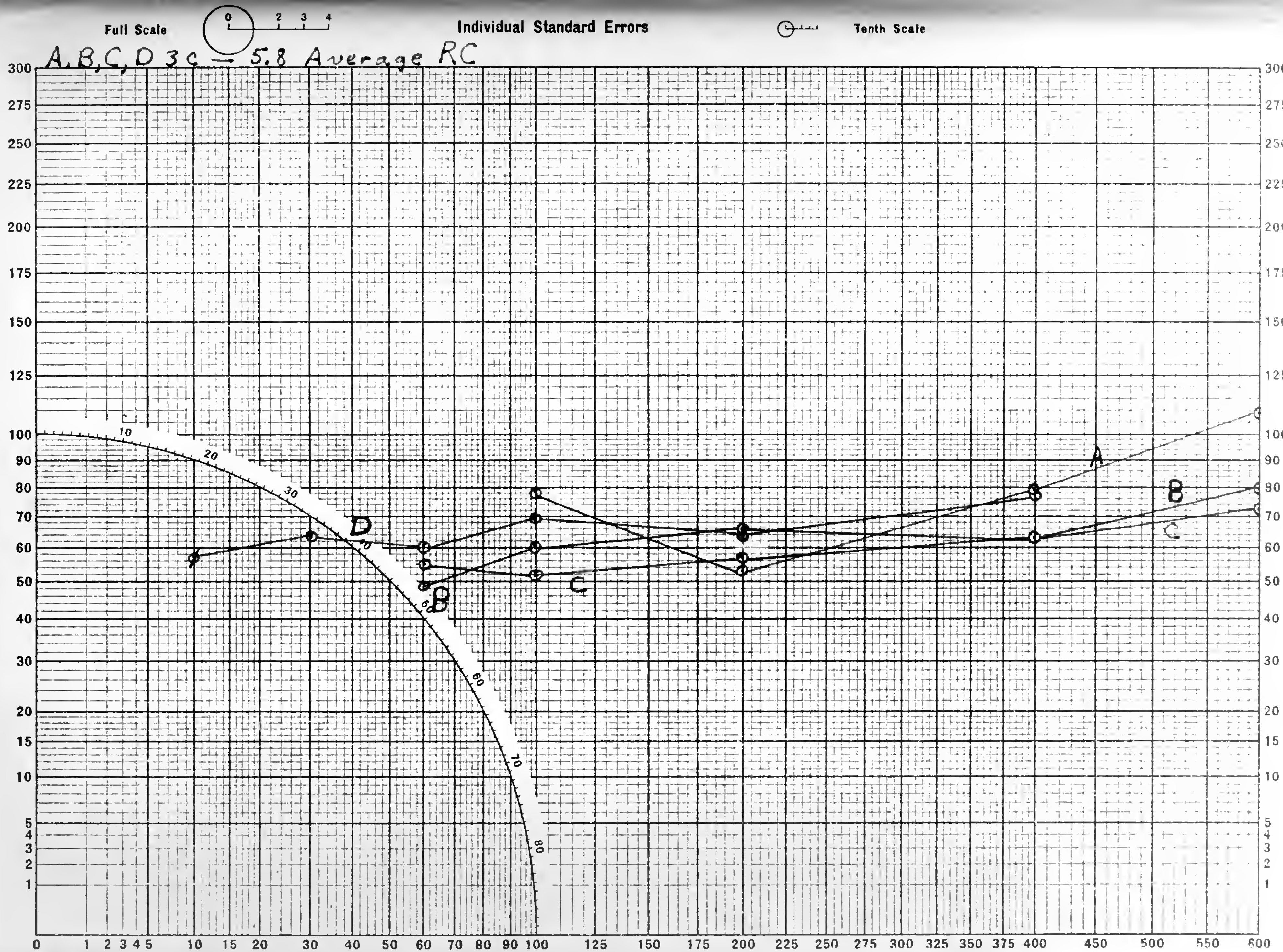
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 3b — 4.8 Average RC
A
B
C
D



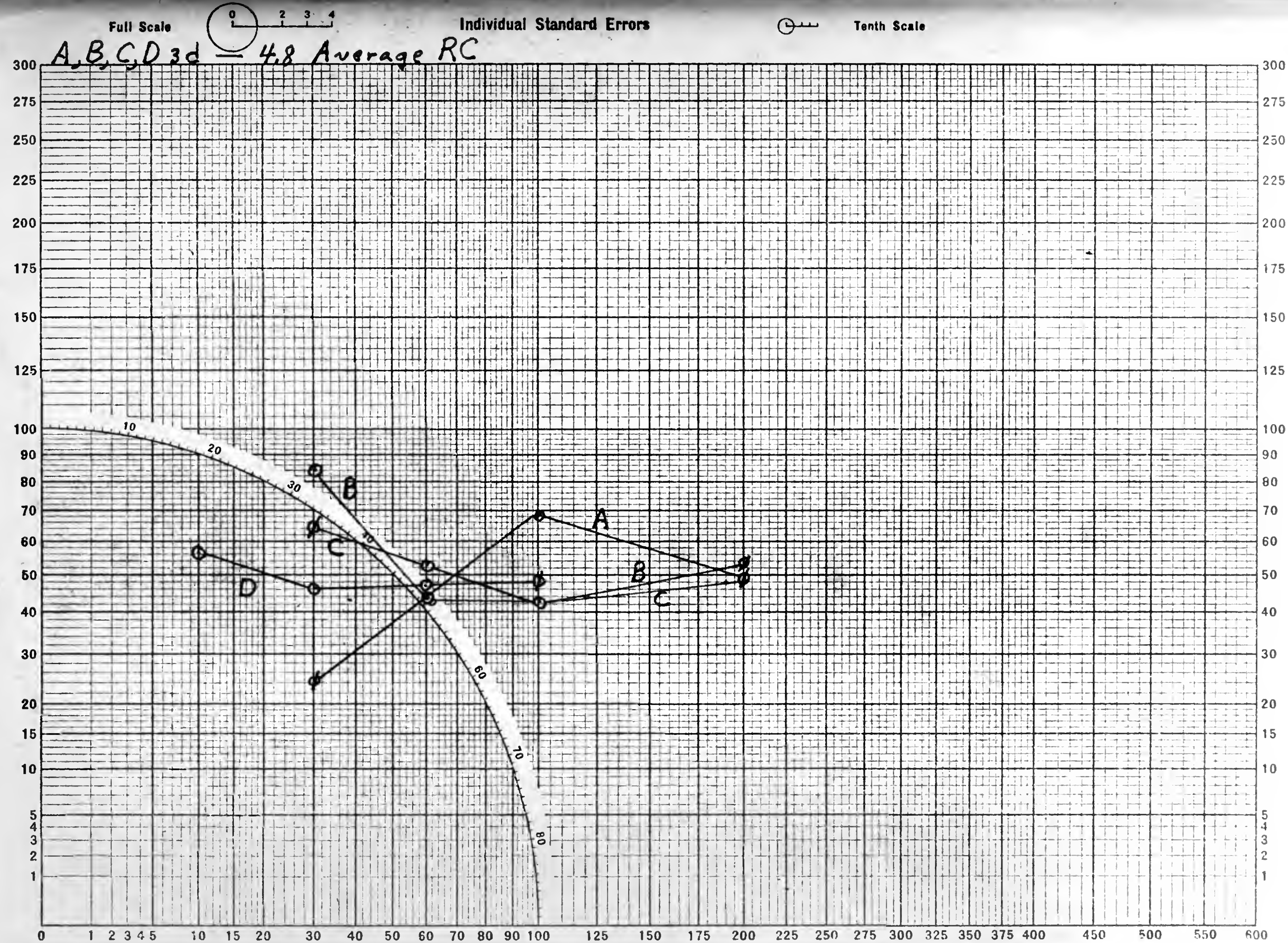
Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A, B, C, D 3b — 5.8 Average RC
D
B
A
C
B
C

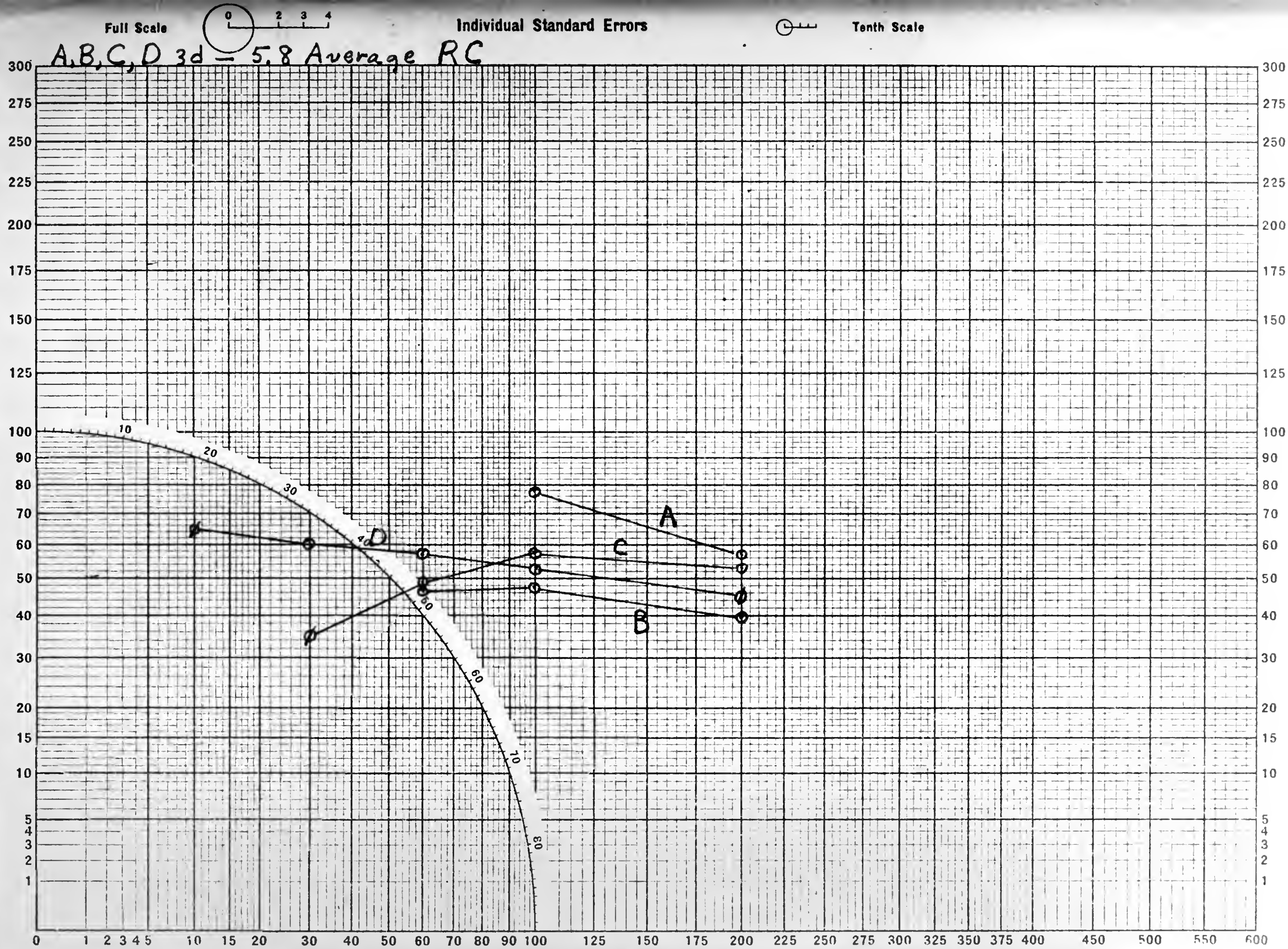


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
A, B, C, D 3c — 4.8 Average RC
A
B
C
D
B+C



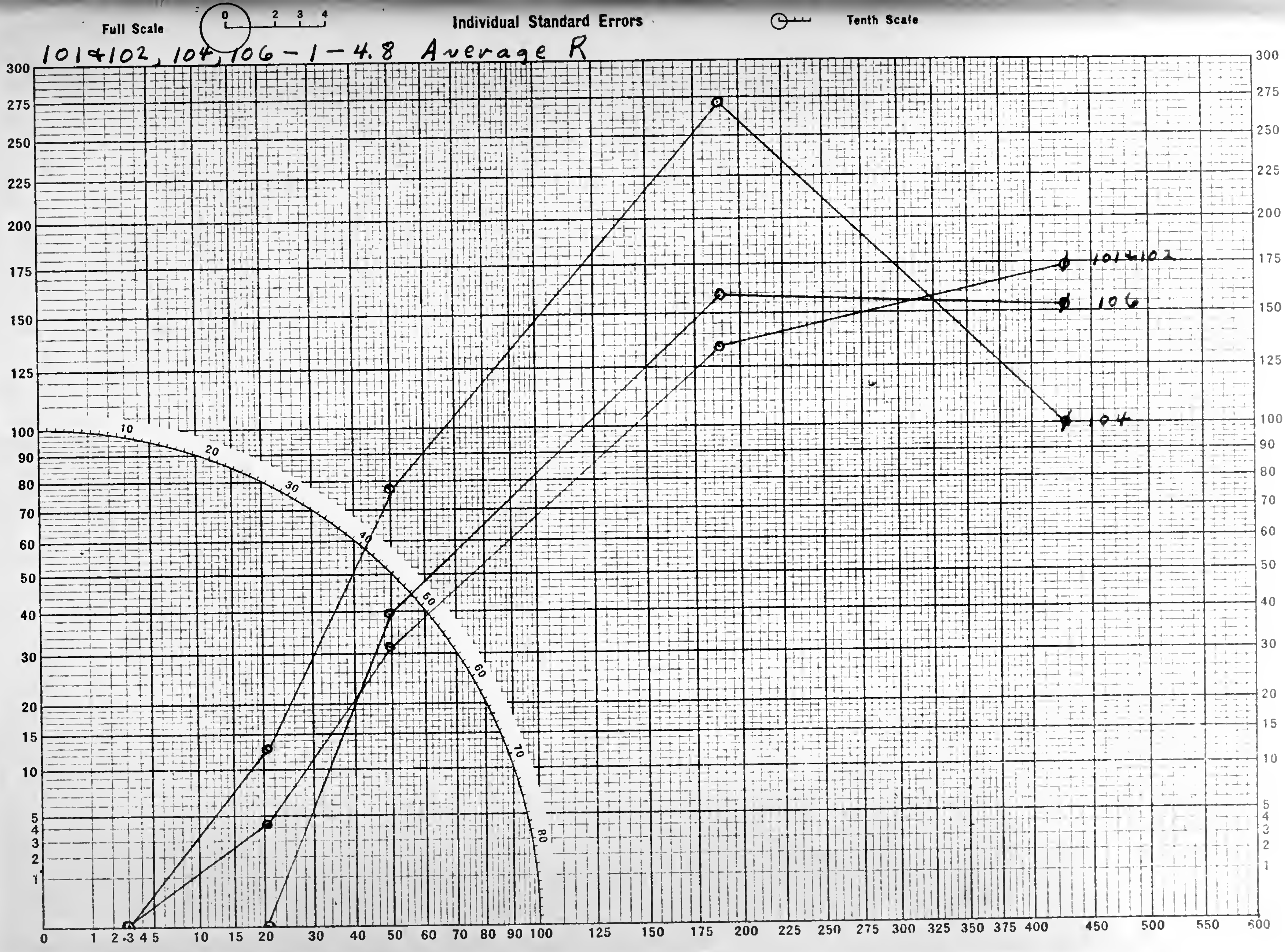
Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 3c — 5.8 Average RC
A
B
C
D


Full Scale
Individual Standard Errors
Tenth Scale
A, B, C, D 3d = 4.8 Average RC
A
B
C
D

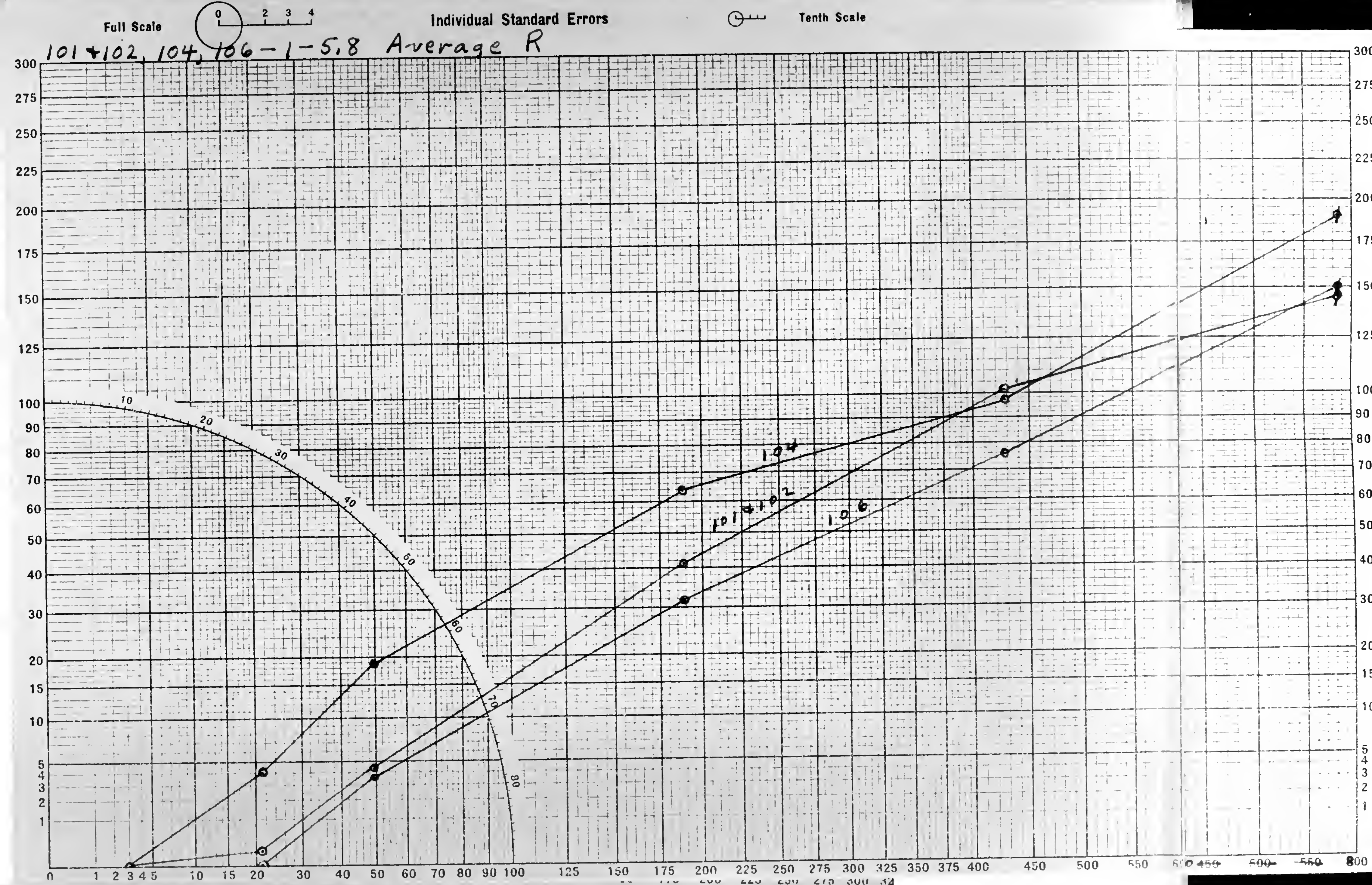


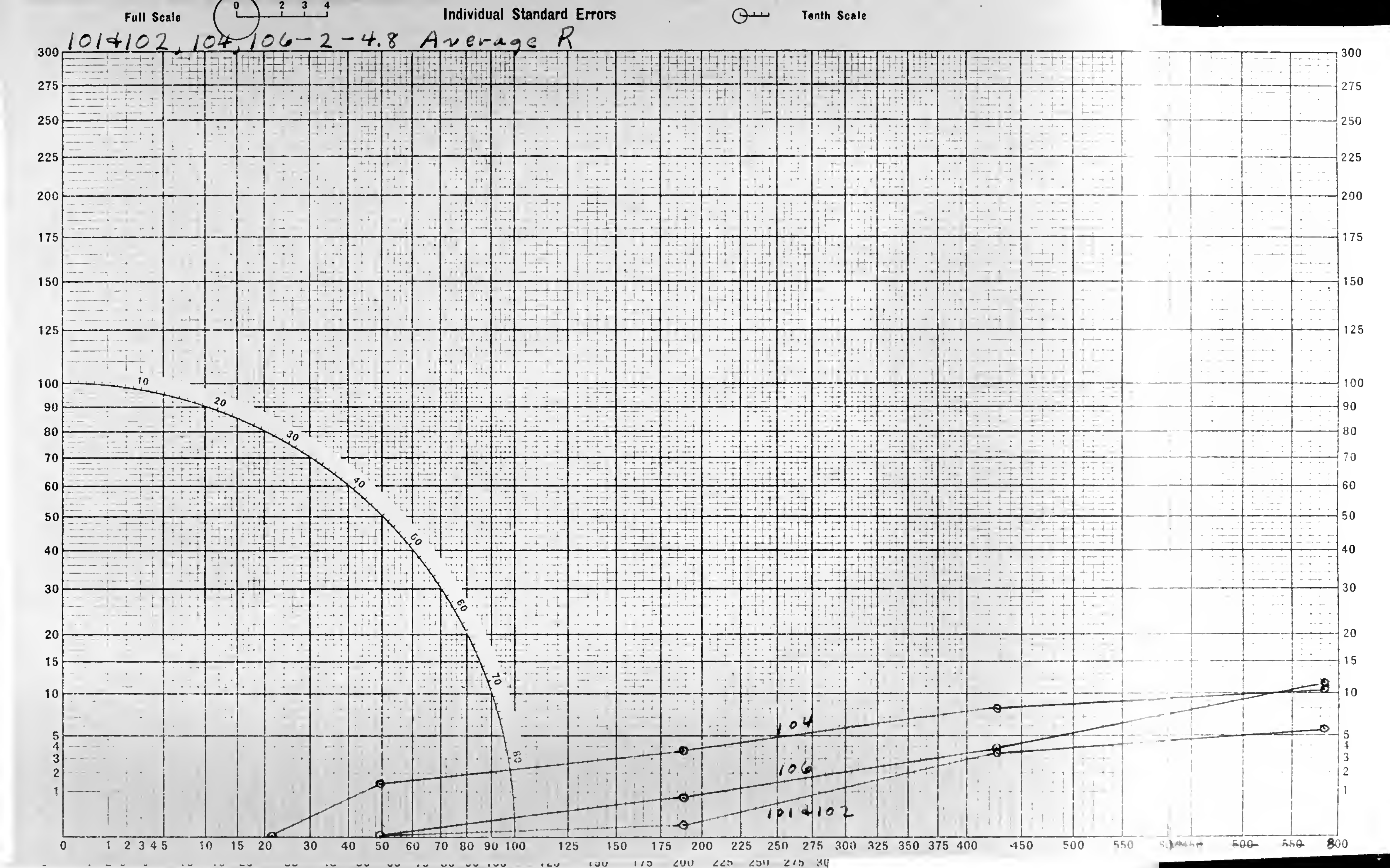
Full Scale
Individual Standard Errors
Tenth Scale
A,B,C,D 3d = 5.8 Average RC
A
B
C
D

AVERAGE RESISTANCE, COMPARING
PREVIOUS LIFE EXPERIENCE EFFECTS
IN THE TUBES RECEIVED WITH 1000 HOURS
LIFE

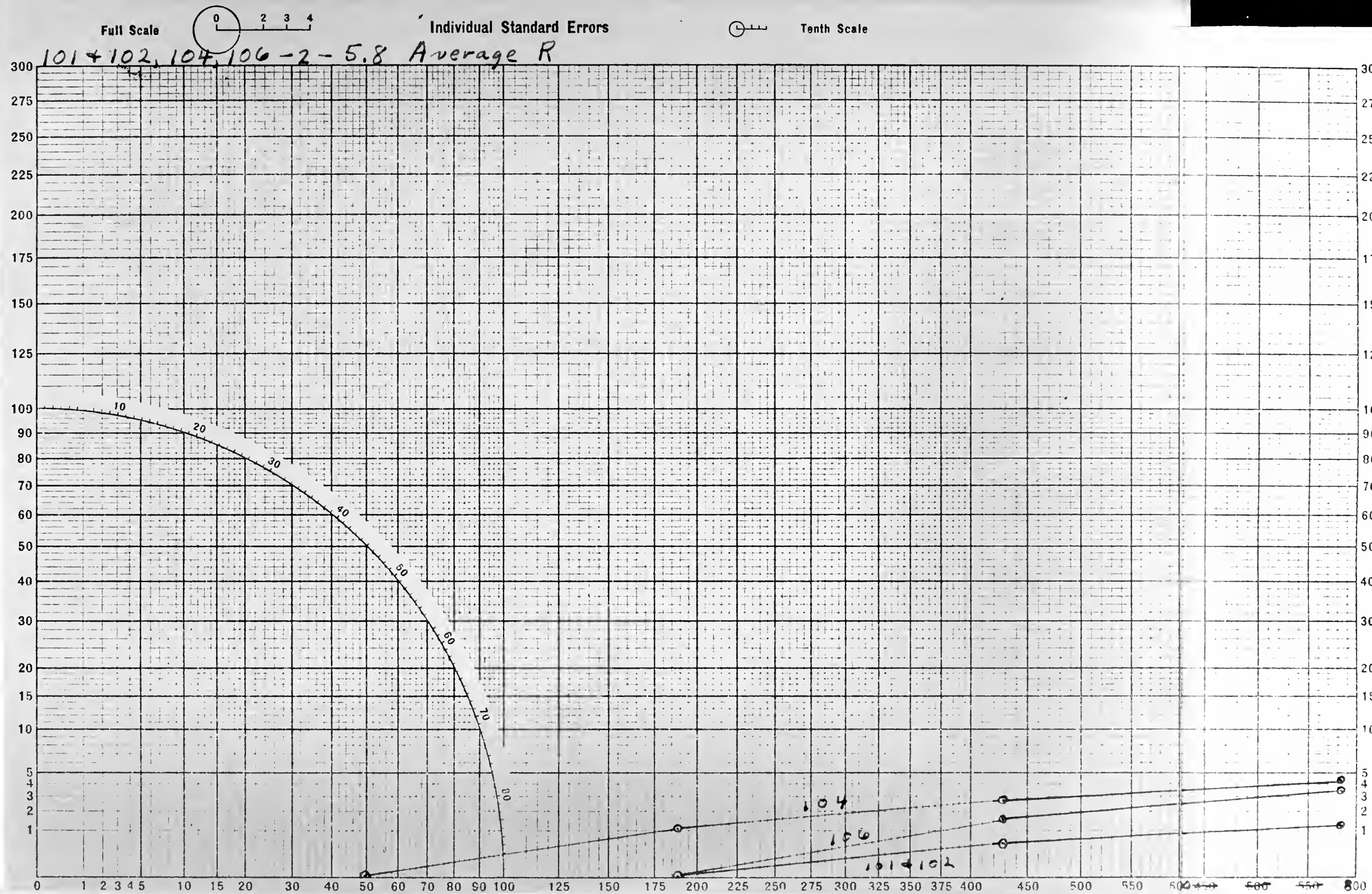


Full Scale
0 2 3 4
Individual Standard Errors
Tenth Scale
101+102, 104, 106-1-4.8 Average R
101+102
106
104


Full Scale
Individual Standard Errors
Tenth Scale
101+102, 104, 106-1-5.8 Average R
104
101+102
106



Full Scale
Individual Standard Errors
Tenth Scale
101+102, 104, 106-2-4.8 Average R
104
106
101+102



Full Scale
Individual Standard Errors
Tenth Scale
101 + 102, 104, 106 - 2 - 5.8 Average R
104
106
101 + 102

APPENDIX IV

CATHODE PHOTOGRAPHS

The following nine pages are reproductions of photographs of cathodes at various stages in life. The dark smudge at the surface of the cathode nickel is a residue from the polishing wheel which has become packed into the depression at the metal-coating boundry. This depression results from the fact that the nickel is harder than the coating or the Castolite and so in the polishing process the softer material is removed to a greater depth than the nickel. Thus far no effective means has been found to remove this deposit and so the region of primary interest - The Cathode Nickel-Coating Interface - is obscured.

In each of the cross section photographs the white area at the bottom of the picture is the nickel sleeve and the hazy white region above this is the emissive coating. The photographs were made at 500X and the enlargement in printing was 2X. The scale on these pictures is then 1000X normal size.

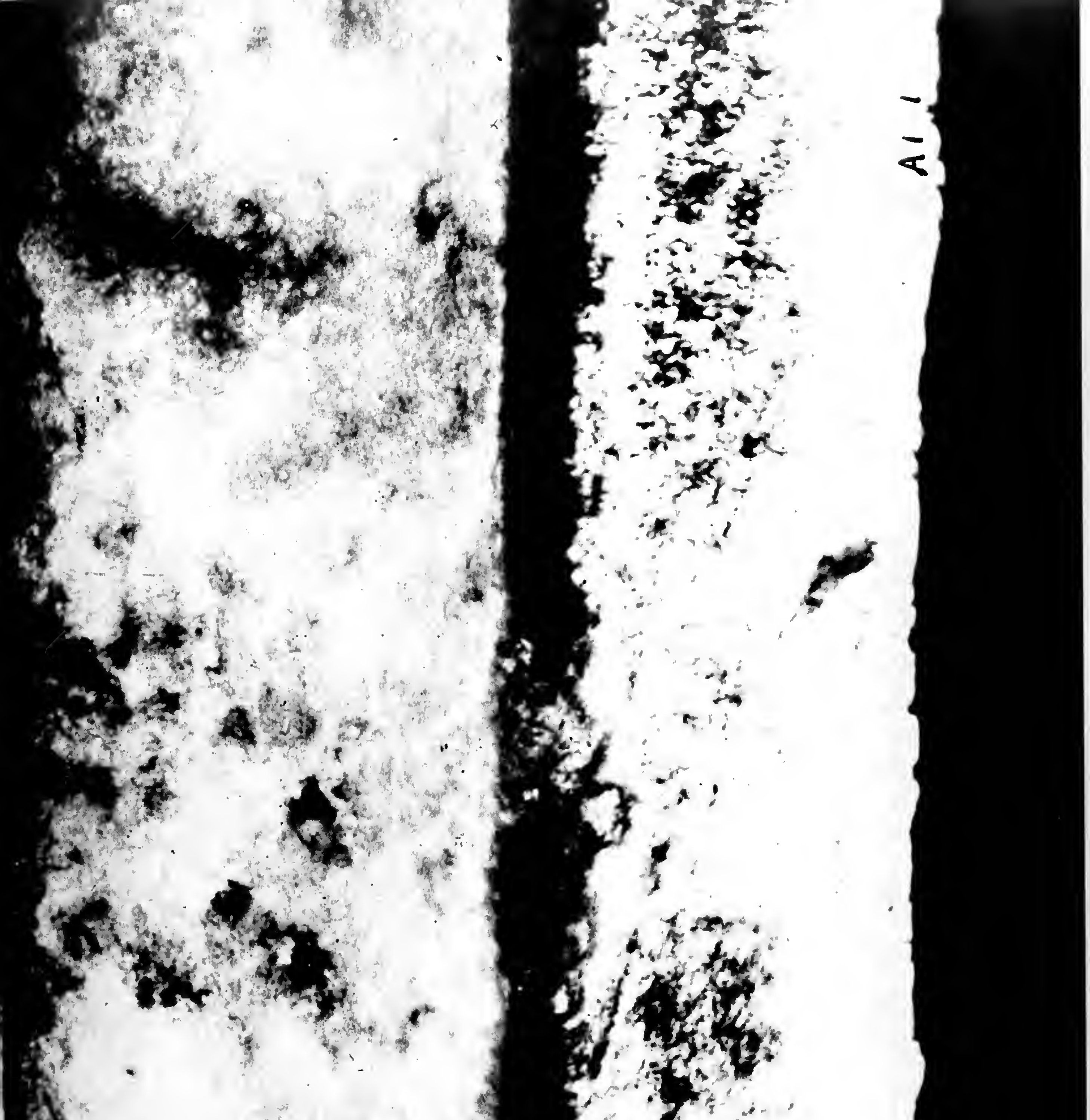
The first five pictures are arranged in order of age and show the coating condition prior to processing-E11, after activation but before stabilization-A11, after stabilization-B12, after 60 hours "previous life" -C12, and after 300 hours "previous life" -D11.

The picture of a cathode from tube B3c1 shows the condition of the coating after 600 hours of cut-off life. The picture of a cathode from tube B3d5 shows the condition of the coating after only 200 hours of low current operation. Tube B4 42 was operated in the 3a condition but with a

[illegible]

grid return resister of 47,000 ohms to reduce the effect of grid emission. The photograph of this tube's cross section shows the effect of high temperature operation with normal current flow.

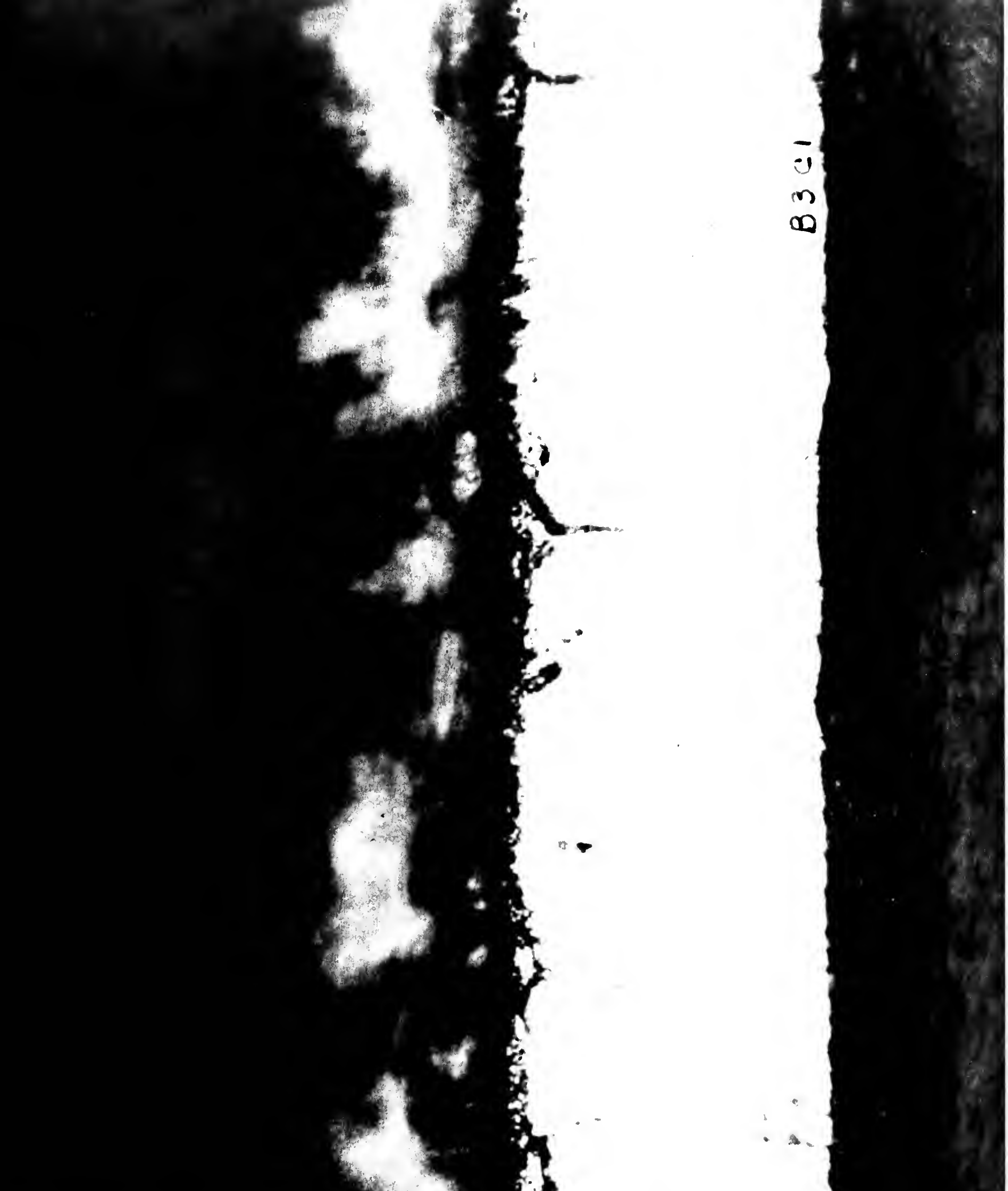
The picture of the surface of tube C3c2 cathode shows the appearance, at the left, of the region where the coating has been brushed off with a piece of paper. At the right the appearance of the uncoated portion of the cathode sleeve is shown. Some trace of the grain structure is visible as a result of sputter etching of the hot cathode metal. Tube C3c2 had completed 600 hours of cut-off operation following a 60 hour "previous life" experience.


Al 1


B12

C12

D11


B3 C1


B3d5


B4 42


C3c2

APPENDIX V

MELT LOT ANALYSIS

CATHODE SPRAY

AGEING SCHEDULE

1. Spectroscopic analysis of Cathode Nickel Melt Lot #90.

C			
Fe	0.04%	0.2% max.	ASTM
Si	0.03%	0.01-0.05%	
Mg	0.029%	0.01-0.1%	Specification
Mn	0.12%	0.2% max.	
S			for Normal
Cr	0.02%		
Co	0.082%		Cathode Nickel
Ti	0.018%	0.023% max	
Cu		0.2% max.	

2. Materials list for Double Carbonate Cathode Spray *H1 1N.

a.	Double Carbonate	KR0422
b.	Nitrocelulose "A" Binder	13700K-H2-1A
c.	Amyl Acetate	KR0148 D5E14
d.	Diethyl Oxalate	KR0173
e.	Methanol	KR0199 D5B51A

3. Z-2177 standard ageing schedule.

1.	Eh = 8V.	1 min.
2.	Eh = 12V.	2 min.
3.	Eh = 8V.	5 min.
4.	Eh = 7V., Ib = 15MA.	5 min.

APPENDIX VI

LIFE SHELF SCHEMATICS

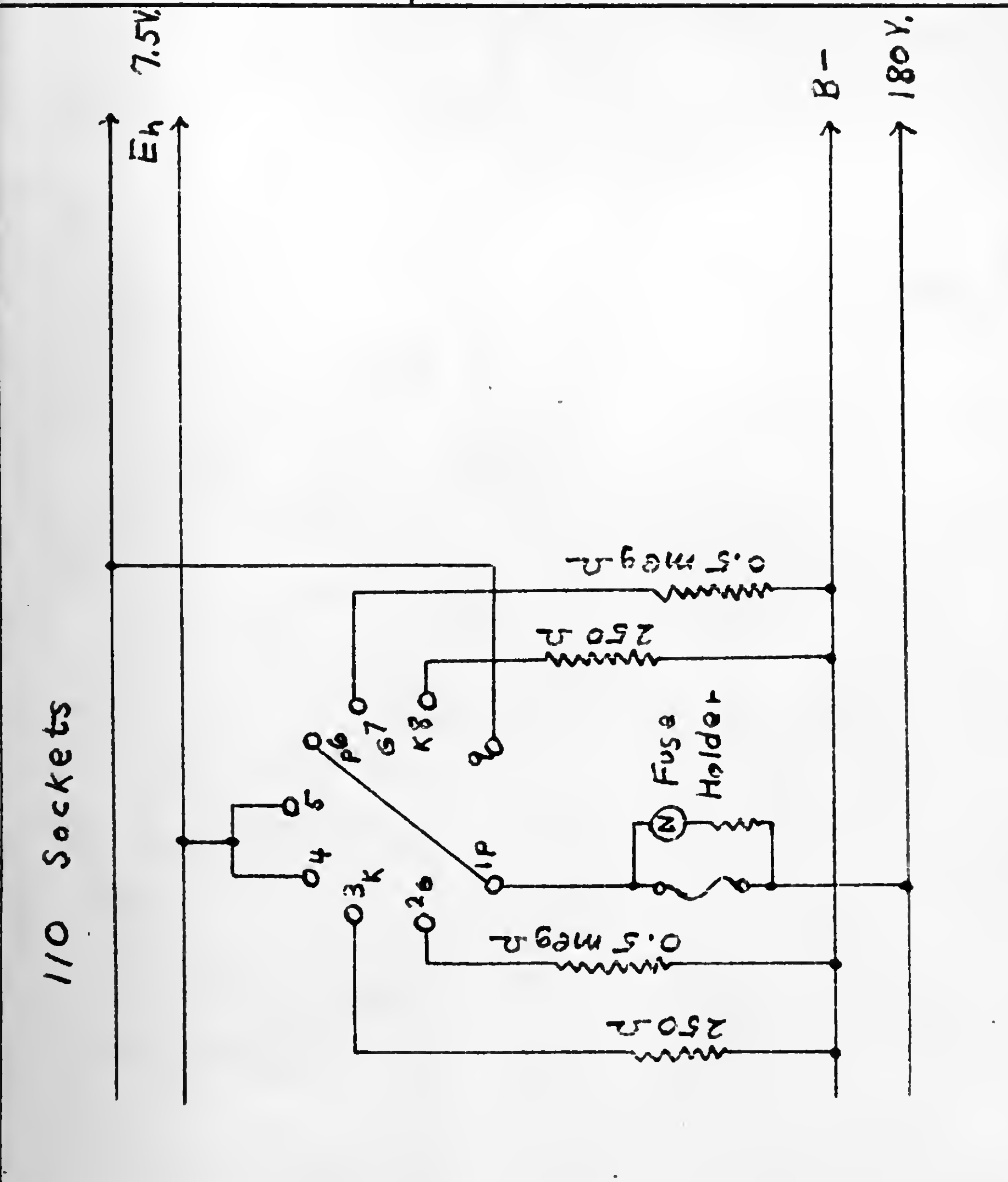
The first three of the following schematic diagrams are the construction schematics for the special life shelves used for the main group of tubes. They are accurate except for the omission of parasitic suppressors in the form of small resistances in the individual plate and grid leads and bypass condeners. They show the method of obtaining the desired operating characteristics without the additional clutter of the auxiliary circuit elements.

The fourth schematic diagram is of the shelf used for the small group of tubes received with 1000 hours life.

GENERAL ELECTRIC

REV NO.	TITLE Z-2177 Special Life Shelf - 2a	CONT ON SHEET	SH NO.
CONT ON SHEET SH NO.	FIRST MADE FOR		

REVISIONS



Insulate Grid Pins (2-7)
One Fuse Holder per Five Tube String

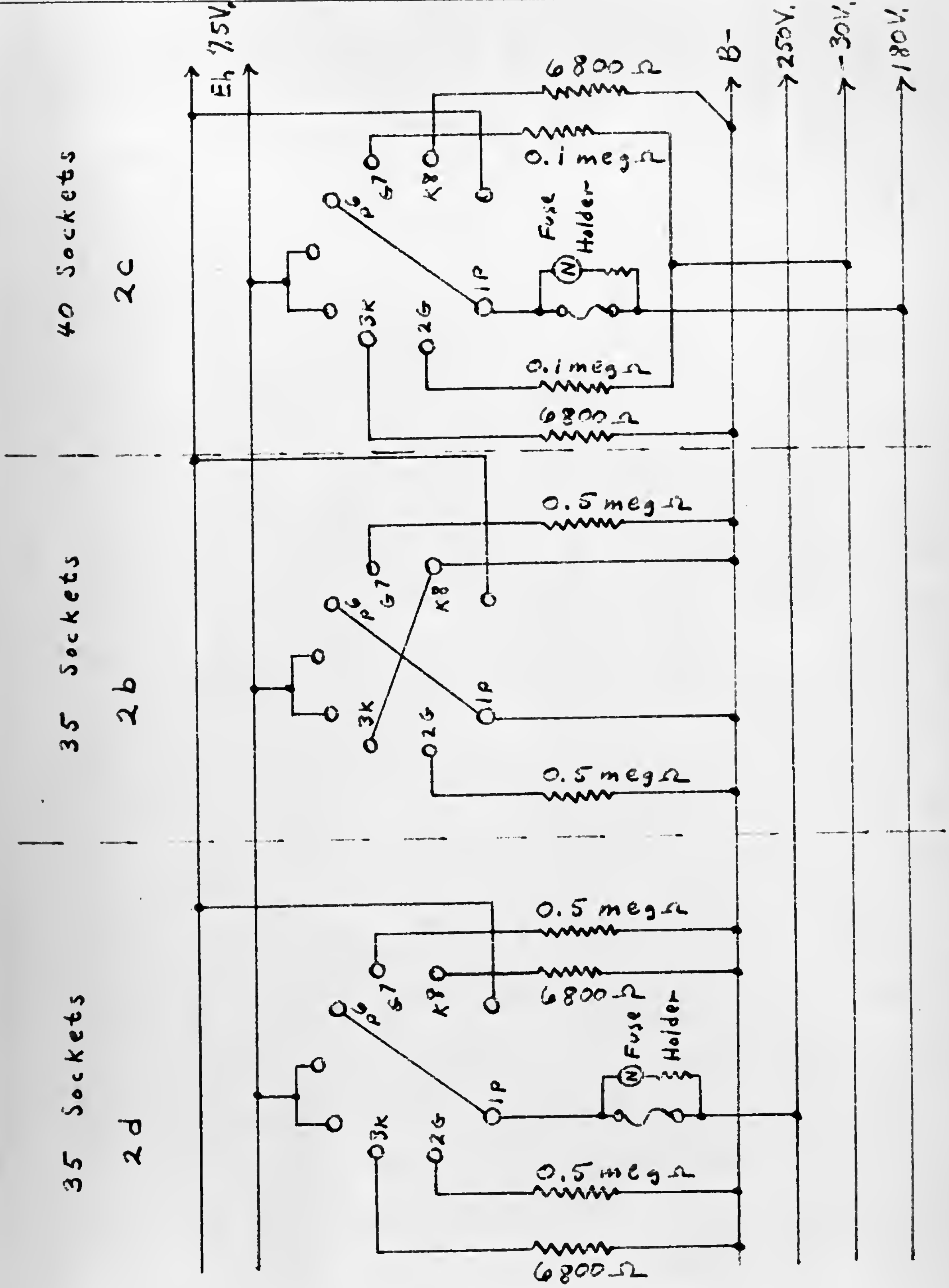
PRINTS TO

MADE BY	APPROVALS	DIV OR DEPT	
ISSUED		LOCATION	CONT ON SHEET SH NO.

PRINTED IN U.S.A.
FF-803-W2-P (11-53)

GENERAL ELECTRIC

REV NO.	TITLE Z-2177	CONT ON SHEET	SH NO.
	Special Life Shelf - 2b, 2c, 2d		
CONT ON SHEET SH NO.	FIRST MADE FOR		



Insulate Grid Pins (2-7)
Split Shelf 3 Ways as Indicated
One Fuse Holder Per Five Tube String

REVISIONS

PRINTS TO

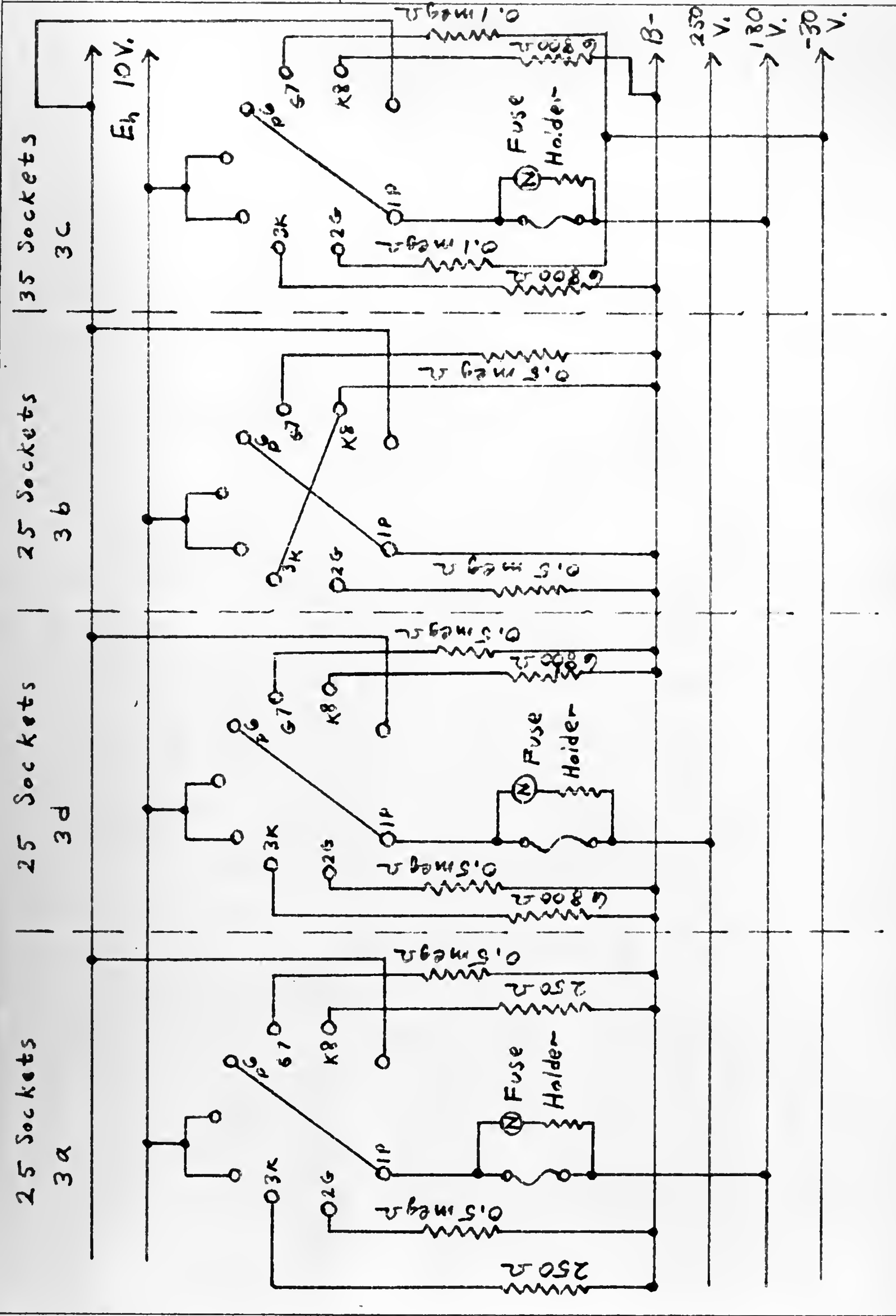
MADE BY	APPROVALS	DIV OR DEPT.	
ISSUED		LOCATION	CONT ON SHEET SH NO.

FF-803-W2-P (2-54)
PRINTED IN U.S.A.

GENERAL ELECTRIC

REV NO.	TITLE Z-2177	CONT ON SHEET	SH NO
	Special Life Shelf - 3a, 3b, 3c, 3d		
CONT ON SHEET SH NO.	FIRST MADE FOR		

REVISIONS



Insulate Grid Pins (2-7)
Split Shelf 4 Ways as Indicated
One Fuse Holder per Five Tube String.

PRINTS TO

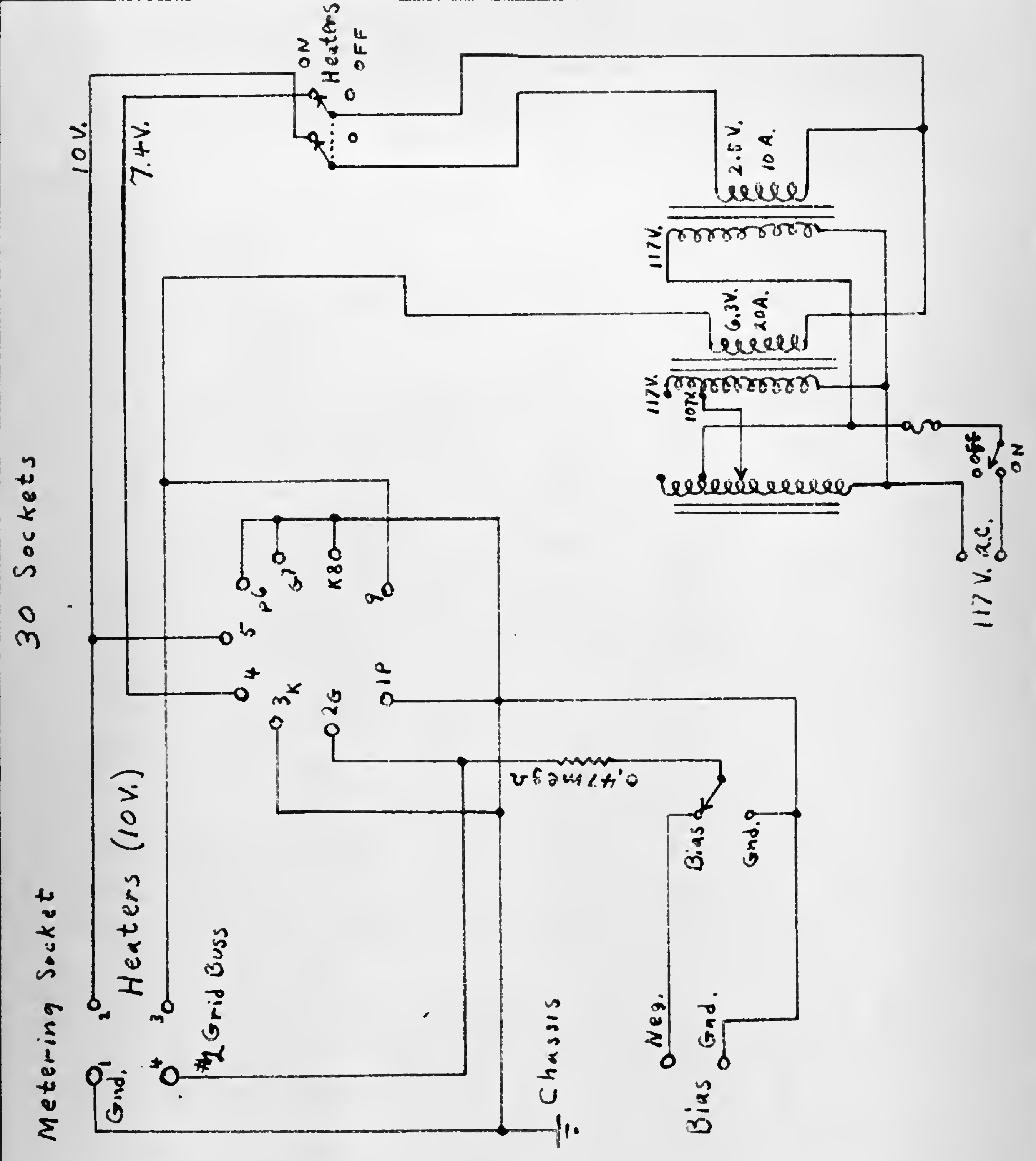
MADE BY	APPROVALS	DIV OR DEPT.	
ISSUED		LOCATION	CONT ON SHEET SH NO.

FF-803-W2-P (2-54)
PRINTED IN U.S.A.

GENERAL ELECTRIC

REV NO.	TITLE Z-2177 Special Life Shelf — 2 Heater Voltage, Zero or Bias - Split Socket	CONT ON SHEET	SH NO
CONT ON SHEET ,SH NO.	FIRST MADE FOR		

REVISIONS



PRINTS TO

MADE BY	APPROVALS	DIV OR DEPT.	
ISSUED		LOCATION	CONT ON SHEET SH NO.

FF-803-W2-P (2-54)
PRINTED IN U.S.A.

APPENDIX VII

PYROMETER TEMPERATURES ON RACK

Tube	Section	Temp. (°C)		Tube	Section	Temp. (°C)	
A2a1	1	802		#A3a2	1	907	(looks almost bare)
B2a1	1	795	Ave. 794	#B3a1	1	908	Ave. 902
C2a1	1	794		#C3a1	1	922	
D2a1	1	785		*D3a1	1	840 -2 870	
A2b1	1	775		#A3b2	1	940	
B2b2	1	740	Ave. 752.5	B3b1	1	918	Ave. 927
C2b1	1	755		C3b1	1	910	
D2b1	1	740		D3b1	1	940	
A2c1	1	748		#A3c2	1	905	
B2c1	1	755	Ave. 751.8	B3c1	1	907	Ave. 908
C2c1	1	756		C3c1	1	920	
D2c1	1	748		D3c1	1	900	
A2d1	1	745		#A3d1	1	910	
B2d1	1	766	Ave. 760.2	#B3d1	1	920	Ave. 913.5
C2d1	1	770		#C3d1	1	914	
D2d1	1	760		D3d2	1	910	

7.5V. Average---- 765.3°C   10V. Average-----912°C

Instrument: Pyro Micro Optical Pyrometer, Serial No. M4123

# Indicates tubes retired because of slumping or having run away on the racks.

* Indicates tube not placed in service in condition indicated, having only "previous life" experience.

Data was obtained on 22 February 1955.

28452
Thesis
H714
Holmes
Cathode interface impedance
growth at elevated temperature.